Author's response

This file includes;

1. Line by line reply to referees' comments
2. Line by line changes made in the manuscript
3. Track changes to the revised version of manuscript

Responses to Referee #1

We thank the Reviewer very much for the constructive and helpful review. Our responses to individual comments and suggestions for revisions are outlined below.

General comments:

This study reveals interesting results on farmers' perception and willingness / opportunity to adapt to climate change from a vulnerable region. The research questions are stated clearly. Though, the introduction contains repeating information and should be shortened. The conclusion section basically repeats arguments from the discussion. The concluding sentences are rather general and not closely connected to the findings. Here, the conclusion should be rewritten more concisely.

> ***Answer:*** Thank you very much for your positive feedback. The introduction and conclusion section has been improved as per your suggestions.

Specific comments

p. 1361, l.3: what is meant by "yield", is it yield per area, overall production, or production per capita?

> ***Answer*:** Here, yield refers to productivity measured in tons per hectare. This description has been included in the text to make it clear.

p. 1362, 2nd paragraph: This paragraph can be integrated into the previous text.

> ***Answer*:** The introduction part has been improved and the mentioned paragraph has been integrated into the previous text.

p. 1362, l. 26-28: the information "and their adaptive behavior which is imperative to understand climate change adaptation in agriculture because farmers are the primary decision makers and stakeholders in the agriculture sector." Should be integrated into the previous text, where reasons for the importance of farmers with respect to climate change adaptation are given.

> ***Answer*:** The introduction part has been improved and the mentioned paragraph has been integrated into the text mentioned in the comment.

p. 1363, 2nd paragraph: The research questions are clearly stated. But the information afterwards partly is a repetition of previous arguments. It should be shortened.

> ***Answer:*** We revised the section and reduced repetitions as suggested.

p. 1369, l. 12: Why Zone D and not C?

> ***Answer:*** Zone C is also an important zone to be considered but due to limited budget and time, it was not taken as study area. The reason for not selecting Zone C lies in its resemblance of some attributes with Zone D such as existence of Desert areas, crops grown in both areas and irrigation system prevailing in both zones.

p. 1369, l. 18-19: "based on the agriculture share to the total national economy, weather and climatic conditions, cropping patterns and irrigation networks in the area."

It should be explained whether a wide range of climatic conditions, cropping patterns, etc. was searched for or homogeneous conditions.

> ***Answer:*** We tried to select areas with diversity in the above mentioned factors. For this purpose we searched the different agro-ecological regions. We also tried to get a good representation of the province regarding crop, irrigation system, climate etc. For example, Gujrat district belongs to the rain-fed region and is very different from the other two regions in terms of the cropping pattern and irrigation systems. Climate indicators also differ from the other two regions.

p. 1369, l. 20: Which criterion?

> ***Answer:*** This question has been clarified in the revised text. We developed a criterion to select union-councils (UCs) for the sampling. In this criterion, first we excluded the urban UCs and in next step we randomly choose 20% of the remaining UCs as sample UCs.

Suggestion: I suggest to place section 3.2 before 3.1. so that the reader first understands the study region. Then, it is clearer, why the particular features were used to select the villages.

> ***Answer:*** Your suggestion is sensible. Accordingly, we have shifted section 3.2 before section 3.1 as suggested.

p. 1371, l. 14-24: This paragraph repeats information from the introductions and partly from the methods section. It should be omitted.

> ***Answer:*** We revised the section and reduced repetitions.

p. 1372, L. 22-23: "Overall decrease in responses from perception to adaptation stage was 29 %." Does that refer to 81% of all farmers perceived some kind of climate change (l. 12), but only 52% really adapt (81%-29%)? If so, this sentence should be corrected, because this is not a decrease by 29%, but a drop from 81% to 52%.

> ***Answer:*** The sentence has been corrected according to your suggestion.

p. 1373, l.10: Why is renting out land an adaptation to climate change?

> **Answer:** Renting out land is a relative severe adaptation measure. However, in the context of this study, renting out does not include fully renting out land to someone instead it means that due to climate variability or climate related risks, some farmers rent out some of their land to other farmers and do some off-farm activities. So it may be considered as adaptation to climate variability.

p. 1374, l. 4-7: "The major constraints identified by the majority of the respondents (Fig. 6) were the lack of information (44%) and lack of money (22%) followed by resource constraint (17 %), shortage of irrigation water (14 %) and other constraints (2 %)."

Were those constraints asked one after the other in the questionnaire, as is was a fully structured one? If so, it should be explained, why those constraints were chosen (pretest period for the questionnaire?).

Answer: We listed six to seven major constraints in the questionnaire. We first asked the farmers without giving particular choices. If farmers don't know the answer then we asked constraints explicitly one after the other.

These constraints were selected based on pretesting, literature review and previous studies on farm level adaptation or adoption of certain technologies. See following studies for reference;

Baumüller, H. Facilitating agricultural technology adoption among the poor: The role of service delivery through mobile phones. Working paper series 93. Center for Development Research, University of Bonn, 2012.

Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., and Herrero, M.: Adapting agriculture to climate change in Kenya: household strategies and determinants, J. Environ. Manage., 114, 26–35, 2013.

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., and Yesuf, M.: Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia, Global Environ. Change, 19, 248–255, 2009

Hanif, U., Syed, S. H., Ahmad, R., Malik, K. A., and Nasir, M.: Economic impact of climate change on the agricultural sector of Punjab, Pakistan Develop. Rev., 4, 771–798, 2010.

The pretest period for the questionnaire was 1 week.

p. 1374, l. 23-27, like p. 1374, l. 4-7 Figure 1: This figure appears in the introduction. But isn't it a result of this study? If so, it should be placed into the result section.

Answer: Yes the figure shows results of the study. It has been shifted to the results and discussion section as suggested.

Technical corrections

p. 1361, l.2: " food- insecure" -> "food-insecure"

Answer: corrected as suggested.

p. 1361, l.7: "has indexed" -> "has been indexed"

Answer: corrected as suggested.

p. 1363, l. 5-7: "i.e. how farmers perceive long term changes in surrounding climate and how they adapt their farming in response to perceived changes in climate?" -> "i.e. how do farmers perceive long term changes in surrounding climate and how do they adapt their farming in response to perceived changes in climate?"

Answer: corrected as suggested.

p. 1368, l. 6: "thee" -> "the"

Answer: corrected as suggested.

p. 1370, l. 5-6 "in selected union councils of three study districts of Punjab." can be omitted.

Answer: corrected as suggested.

<u>p. 1372, L. 20-22:</u> “As can be observed from the results, from perception stage to intention stage an 8.2% reduction was observed in responses while from intention stage to adaptation stage, responses of farm households were reduced by 22.6 %.” This sentence should be reformulated.

<u>Answer:</u> The sentence has been reformulated as suggested.

<u>p. 1373, l. 2:</u> “of 10–20 year“ -> “of the past 10–20 years”

<u>Answer:</u> corrected as suggested.

<u>p. 1375, l. 25:</u> “are having“ -> “had“ Figures 3, 4, 7, 8, and 9: The texts and numbers along the axes and inside the figures are too small.

<u>Answer:</u> corrected as suggested.

Thank you again for the helpful comments. – Authors.

Responses to Referee #2

We thank the Reviewer very much for the helpful and constructive review of our paper. We have addressed all the proposed suggestions and comments in our revised manuscript. Our responses to the individual comments are outlined below.

General comments

This contribution is based on the broadly accepted principle that "understanding how farmers perceive changes in climate and what factors shape their adaptive behavior is desirable for adaptation research".

The originality of the paper resides mostly on the chosen case study. In fact, as stated in the paper "Despite internationally extensive research on agriculture adaptation to climate change, a little work is done so far in South Asia. Similarly in Pakistan, the scope of research on linking climate change to agriculture is very restricted."

Findings from the modeling procedure are robust and support the results and discussion sessions.

The following scheme resumes the main elements presented in this work:

Dataset: Farm household data of 450 households from three districts in Punjab province of Pakistan

Climate challenges: Rising temperatures Floods Droughts Yield losses

Aims: Examine how: farmers perceive climate change farmers adapt their farming accordingly

Results from dataset analysis: 58% of the farm households adapted their farming to climate change

Most common adaptive strategies: Changing crop varieties changing planting dates Plantation of trees changing fertilizer

Factors improving adaptive capacity Education Farm experience Household size Land area Tenancy status Ownership of tube-well Access to market information on weather forecasting Extension

Factors hampering adaptive capacity Lack of information Lack of money Resource constraint Shortage of irrigation water

Method Binary logistic model

Identified policy shortfalls Ineffective climate policy V. low technological, financial capacity in adapting to climate change

Policy-making suggestions Greater investment in farmer education Improved institutional setup for climate change adaptation _________________

Answer: We thank you for your valuable positive comments and review of our manuscript.

Specific comments

Pages/lines: comment

1363-1371: There are overlaps between sections 2 and 3 in that both of them present methodological aspects. Section 2 presents methodological aspects related to modeling. Section 3 presents methodological aspects related to sampling and data collection as well as description of the study area. These two sections could be restructured as follow: 3.2 could be integrated in the introduction, becoming e.g. 1.2 2 and 3 could be merged as 2, where: 3.1 becomes 2.1 2.1 to 2.5 follow accordingly 4 becomes 3 and so forth

> ***Answer:*** We thank you for your suggestion. We merged section 2 and 3 as suggested. Instead of shifting section 3.2 to 1, we put it in the start of section 2 as 2.1 and other sections were changed accordingly. This was done to separate the methodology part from the introduction part.

1370/1: The presence of table 2 here suggests that an arrangement similar to that proposed above has previously been considered.

> ***Answer:*** Now sections have been rearranged and we put section 3.1 and 3.2 at the beginning of section 2.

1363/23: Adaptation is a term with a very long trajectory of use across disciplines. Here you should specify the field/domain to which you are referring before stating “Adaptation is a way to avoid losses due to increasing temperature and decreasing precipitation (Hassan and Nhemachena, 2008).”

> ***Answer:*** We revised the definition as suggested.

1364/4-7: Economical and risk factors are the only ones considered to affect household adaptive choices in the present model: “we assume that farm households will choose to adopt certain adaptation measure only if they perceive reduction in risks to crop production and increase in net farm benefits associated with adoption of a particular measure”. No cultural traits are considered to affect household choices in the present study. This is fine as long as it is clearly stated, or otherwise taken into account (i.e. by introducing uncertainty in the decision making process), and perhaps shortly justified.

> ***Answer:*** We have included district dummies which not only incorporate the agro-ecological zones but they may also consider cultural traits which are different in all three regions. We included little description in section 2.3 line 1366/6.

1400/Figure 3: It may be useful to add a figure here presenting actual (measured) changes in summer/winter temperature and precipitation over a given time (which should correspond to the estimated time of meteorological/climatic memory applied in this study, i.e. c. 10/20 years according to 1371/20)

> ***Answer:*** Thank you for your suggestion. We will consider to add a figure according to your suggestions.

1373/10-14: It is unclear whether or not this statement is based on answers from the interviews. In this sense, it would be useful to have a table/image presenting a sample of the questionnaire used for interviews.

Answer: This statement is not based on the answers from the interviews instead it is based on literature and constraints faced by farmers shown in fig. 6.

1373/18-20: Idem

Answer: This assumption was based on the fact described earlier in section 3.2 line 1371/10 that Gujrat district is mainly rain-fed and dependent on rainfall or groundwater for farming activities.

1377/20: "schooling of the household head" is a powerful explanation factor in this model. In the introduction you could perhaps briefly introduce how households are organized in the region/districts of study: e.g. average number of members, composition, structure, "head", internal hierarchies relative to decision-making,: : :

Answer: The household structure is briefly described in section 2.3. Particularly,

"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 land holding size (in acres) varies to some extent in district Rahim Yar Khan (18), Toba Tek Singh (14) and Gujrat. A little variation is also found in average household size (9-10) and years of schooling (8-9) in all three districts. In terms of agriculture as the main source of income, all three regional districts Rahim Yar Khan (85%), Toba Tek Singh (79%) and Gujrat are different"

1378/6: it is difficult to imagine a 1% increase in household, unless households are made of 100+ members. It may be more useful to present these data in terms of increase in members, e.g. "an increase in one member of the average household: : :".

Answer: Thank you for your suggestion. We revised the description according to your suggestion.

1379/14: Information nowadays is mostly passed via mobile telecommunications (phones and internet services). Would perhaps "Access to telecommunication technologies" be a more robust indicator of access to information than proximity to market.

Answer: We used this indicator based on literature and local settings. Access to telecommunication technologies is also an important factor to include. But we did not use this indicator directly because we already have indicators of access to marketing services and access to weather forecasting information which may serve the purpose of access to telecommunication technologies. Mainly farmers get the weather forecasting information from telecommunication sources (mobile phones, television, radio or internet) as we learned from our survey.

1379/24-25: Within the same sentence, changing crop type is said to be positively and negatively correlated to access to farm credit

Answer: Thank you for your comment. It was a typing mistake. We wrongly put the changing crop variety instead of changing crop type in the start of sentence. It was only the changing crop variety which is positively correlated to access to farm credit. We have also corrected the mistake in text.

1380/10: conclusive sentence is missing in this section (4.5.10)

Answer: We added a conclusive sentence in the section 4.5.10.

1381/17: idem

Answer: We added a conclusive sentence in the section 4.5.10.

1383/4: Clarity of the conclusions may perhaps be improved by some rephrasing and the presentation of the main findings of the study as bullet points

Answer: thank you very much for your valuable suggestion. We have improved conclusion of the study as per your suggestions.

Technical corrections (TC)

TC1: Although I have tried to address some of the typos and grammatical issues in the text, a further revision/editing by a native English speaker would help clarify some passages in the manuscript (specifically in Sections 1, 4 and 5).

Answer: We thank you for the technical corrections and suggestions. We implemented all the technical corrections and suggestions for improvements in the updated version of manuscript.

TC2: Numbering of tables and figures should be revised as tables and figures in the text are not always introduced progressively. E.g.: Table 1 is introduced at p. 1366, followed by Table 3 at p. 1367 Figure 1 is followed by figure 3 at p. 1368.

Answer: Thank you for the valuable suggestion. We revised the numbering as suggested.

Pages/lines: comment

TC3: 1361/2: delete space in “food- insecure”

TC4: 1362/17: perceive rather than perceived

TC5: 1362/21: delete “a” before “little”

TC6: 1362/22: delete “on” before “linking”

TC7: 1363/5-7: for clarity formulate the two questions separately

TC8: 1363/10: add “are” before “already”

TC9: 1363/20: “Sect.” should be “Section”

TC10: 1363/20: change to “We conclude presenting: : :”

TC11: 1364/21-22: in two instances “his or her” should be “its” (i.e. for household)

TC12: 1366/23: “measure” should be “measures”

TC13: 1368/26: revise unclear sentence “even: : :stage”

TC14: 1372/25: add “some form of climatic risk” after “perceived”

TC15: 1372/27: delete “the next”, write “Sec-tion”

TC16: 1373/2: delete “long-term”

TC17: 1373/3: delete “by them”

TC18: 1373/6: rewrite as “: : :, the most common adaptation measures: : :”

TC19: 1373/7: delete “the”

TC20: 1373/6 and 17: add “:” after “were”

TC21: 1373/19: add “be” after “may”

TC22: 1373/24: “used” instead of “use”

TC23: 1374/5: delete “the”

TC24: 1374/17-18: “interest” is used in the same sentence in two instances with different meanings making the message unclear

TC25: 1374/25: “;” should be “,”

TC26: 1375/3: “Section”

TC27: 1375/5: “theses” should be “these”

TC28: 1375/6-8: unclear sentence needs reformulating “Hence, we assume that perceptions, intentions to adapt and adaptation to climate change differ both in term of extent and decision to choose different adaptation measures.

TC29: 1375/12: “term” should be “terms”

TC30: 1375/19: change as follows: “schooling were more likely (44.2%) to perceive changes in climate over the past 10-20 years than farmers: : :”

TC31: 1376/4: idem

TC32: 1375/25: “had” instead of “are having”

TC33: 1376/15-71: modify as follows “In summary, the higher the level or education and farming experience for a given household, the higher its probability of adaptation to climate change.

TC34: 1402/Figure 5: in the legend “total” should be “average” or “mean”

TC35: 1377/7: change to “in years of experience”

TC36: 1377/10: Begin sentence as follows “Results from this study are in accor-dance with those from: : :”

TC37: 1378/2: use “more” instead of “higher”

TC38: 1378/13: use “held’ instead of “holds”

TC39: 1378/22: use “This” instead of “As”

TC40: 1381/15: use “farmers”

TC41: 1382/8: delete “one exception”

TC42: 1382/14: unclear sentence “: : :both for Rahim Yar Khan respectively which indicates: : :”

TC43: 1382/18: these two sentences should be merged, separated by a “,”: “: : :Rahim Yar Khan. While the lowest elasticity: : :”

TC44: 1383/7: what do you mean by “less uncertain rains”? perhaps “less predictable precipitation patterns”

T45: 1383/7: per-haps you should rephrase “Being mostly rain-fed, agriculture in Pakistan is most likely to be affected by ongoing climate change”

<u>T46: 1384/10:</u> use “by” instead of “with”

<u>T47: 1384/13:</u> I am not sure about the choice to use “improvement” here rather than “betterment”. (“Betterment, making better, is a general term used particularly in connection with the increased value given to real property by causes for which a tenant or the public, but not the owner, is responsible”. Wikipedia)

> ***<u>Answer for TC2-TC47:</u>*** All the above mentioned technical corrections (TC2-TC47) were implemented in the revised version of manuscript.

Thank you again for the helpful comments. – Authors.

Changes made in the manuscript

Here we combine the comments from both reviewers with replies and describe changes made in the text.

1. Over all changes made in the manuscript:

We thank both reviewers for valuable comments and feedback to improve the manuscript. Below is the summery of changes made in the manuscript according to reviewers' suggestion;

1. We integrated some paragraphs in introduction to improve the text and to omit repeated information.
2. We combined section 2 and section 3 into one starting from study area description followed by sampling and data collection and conceptual framework of the model etc.
3. We introduced two new figures to compare farm level perceptions with actual historical trends of temperature and rainfall.
4. We shifted schematic framework to results and discussion part as suggested by one reviewer.
5. We improved conclusion part by omitting repeated information from results and discussion section and giving suggestions based on our results.
6. Description of different terms is added as per reviewers' suggestions.
7. We implemented all the technical corrections suggested by reviewers and also improved the manuscript to avoid any further technical errors.

2. Line wise replies to general comments and changes made in the manuscript

Page (p) and line numbers in old pdf version	Changes made in the revised version	Page and line numbers in revised version
p. 1361, l.3:	We added description of yield in the text.	p. 2 l.15
p. 1362, 2nd paragraph:	We modified the introduction part and integrated the paragraph with previous paragraph.	p.3 paragraph 4 – p.4 paragraph 1
p. 1362, l. 26-28:	Repeated information was omitted	p.4 l. 6-8

p. 1363, 2nd paragraph:	Repeated information is deleted from the text.	P.4 l. 23-25
p. 1363-1371:	We merged section 2 and 3 as per reviewer suggestions. Instead of shifting section 3.2 to 1, we put it in the start of section 2 as 2.1 and other sections were changed accordingly. This was done to separate the methodology part from the introduction part. After modifications, section 2 starts with description of study area (2.1) followed by sampling and data collection (2.2), dependent and independent variables (2.3), marginal effects and elasticities (2.4), description of expalantory variables (2.5) and hypothesis testing (2.6)	p. 5-11
p. 1363 l. 23:	We now described adaptation specifically in the context of agriculture sector.	p. 7 l. 9-10
1364/4-7:	A little description of study districts in section 2.3 was added as per referee's suggestion.	p.9 l. 24-25
p. 1369, l. 20:	We made changes in the text to make sampling process clear	p.6 l.21-23
p. 1370 l. 15	Section 3.2, which was about description of study area, is already shifted above as section 2.1 accordingly.	p.5 l.3
1370/1:	We modified the whole section and now presence of table 2 is according to the text.	p.6 l.26
p. 1371, l. 14-24:	Repeated information is omitted from the text.	p.12 l. 3-11
p. 1372, L. 22-23:	We corrected the sentence according to referee's suggestions.	p. 13 l. 7-13
p. 1374, l. 23-27, like p. 1374, l. 4-7 Figure 1:	We shifted the figure and related text to results and discussion section of the paper under sub-section (3.6).	p. 21 l. 9-28

1377/20:	We added some text to describe households' characteristics across three regions (mentioned below) as per referee's suggestions.	p.5 l.26-32 p.6 l.1-2
1378/6:	We changed interpretation of results (3.5.3.) as referee suggested.	p. 16 l.31 p. 17 l.1
1379/24-25:	Text was corrected as per referee suggestions.	p.19 l.13
1380/10:	We added conclusive sentence in section 3.5.10 as referee suggested.	p.20 l.2-3
1381/17:	We added conclusive sentence in section 3.5.13 as referee suggested.	p.21 l.1-2
1383/4:	We improved conclusion of the study by rephrasing in section 4.	p.22 l.4
1400/Figure 3:	We introduced two figures showing trends of temperature and rainfall in summer and winter season over the period of 20 years in study area as figure 3 (a)-(b). We also compare the perceptions with real trends in 3rd paragraph of section 3.1.	p.41-42/ figure 2-3

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

Muhammad~~.~~ Abid [1,2], Jürgen~~.~~ Scheffran[1], Uwe~~.~~ ~~-~~A. Schneider[3], Muhammad~~.~~ Ashfaq[4]

[1]~~[1] {~~Research Group Climate Change and Security~~ (CLISEC)~~, Institute of Geography~~,~~, University of ~~-~~Hamburg, ~~KlimaCampus, ~~Grindelberg 7, 20144 Hamburg, Germany~~}~~

~~[2]~~[2]~~{~~School of Integrated Climate System Sciences, Grindelberg 5, 20144 Hamburg, Germany~~}~~

~~[3] {~~[3]Research Unit Sustainability and Global Change~~, KlimaCampus~~, University of Hamburg, ~~Bundesstrasse 55~~Grindelberg 5, 20144~~6~~ Hamburg, Germany~~}~~

[4]~~[4] {~~Institute of Agricultural and Resource Economics, University of Agriculture, Faisalabad Pakistan~~}~~

Correspondence to: M. Abid (muhammad.abid@zmaw.de)

Abstract

Climate change is a global environmental threat to all economic sectors, particularly the agricultural sector. Pakistan is one of the negatively affected countries from 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~~of~~ 450 households collected from three districts in three agro-ecological zones in Punjab province of Pakistan, this study examined how farmers perceive climate change and how they adapt their farming in response to perceived changes in climate. The results demonstrate that awareness to climate change persists in the area, and farm households make adjustments to adapt their agriculture in response to climatic change. Overall 58 % of the farm household adapted their farming to climate change. Changing crop varieties, changing planting dates, plantation of trees and changing fertilizers were the main adaptation methods implemented by farm households in the study area. Results from the binary logistic model revealed that education, farm experience, household size, land area, tenancy status, ownership of tube ~~-~~well, access to market information, information on weather forecasting and extension all influence the farmers' choice of adaptation measures. Results

also indicate that adaptation to climate change is constrained by several factors such as lack of information; lack of money; resource constraint and shortage of irrigation water in the study area. Findings of the study suggest the need forof greater investment ionfor farmer education and improved institutional set-up for climate change adaptation to improve farmers' wellbeing.

1. 1 Introduction

Climate change is a global environmental threat and development concerns. Developing countries are 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 is likely to affect the food security in the world by the middle of the 21st century. The largest number of food--insecure people will be located in South Asia (Hijioka, 2014). It is projected that from 2001 to 2059, in Ssouth Asia per hectare cereal yield will decline up to 30 % along with up to 37 % loss in gross per capita water (Parry, 2007) (Parry, 2007).

According to various studies and reports (IUCN, 2009, Kreft and Eckstein 2014, LP 2008), Pakistan is one of the highly affected countries by climate change. Pakistan has been indexed at the 12th place in the Global Climate Risk Index in term of exposure to various extreme climate events over the period of 1993 to 2012 (Kreft and Eckstein, 2014). 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 feeds the 62 % of the rural population (Abid et al., 2011ab; Farooq, 2013). Despite its significant share of the overall economy, this sector is facing serious challenges of 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 is 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 farm level, which can reduce climate vulnerability by taking in rural households and communities better able to set themselves and their farming to changes and variability in climate, avoiding projected damages and supporting them to deal 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 ~~the~~ an ineffective climate policy ~~, the~~and ~~the~~a very low technological and financial capacity of the country in adapting to climate change (Ullah, 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 the some important aspects of the adaptation policy to climate change (Schlenker and Lobell, 2011).

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 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 degree and extent of adaptation methods being taken up by farmers and need~~rooms~~ for further advances in existing adaptation setups. Hence, understanding how farmers perceive~~d~~ changes in climate and what factors shape their adaptive behavior is desirable 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; Brayan 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 different profiles such as research, policy, extension, private welfare organizations, local communities and farmers (Bryan et al., 2013).

A great number of studies have been done on farm level~~ers'~~ adaptation to climate change across different disciplines in various countries ~~that~~ which explored farmers' adaptive behavior and its determinants (Bryan et al. 2009; Deressa et al., 2009; Hassan and Nhemachena 2008; Thomas et al., 2007). ~~Perceiving climate variability is the first step in the process of adapting agriculture to climate change (Deressa et al., 2011).Hence, understanding how farmers perceived changes in climate and what factors shape their adaptive behavior is desirable for adaptation research (Mertz et al., 2009; Weber, 2010).~~

Despite internationally extensive research on ~~agriculture~~ adaptation in the agriculture sector to climate change, ~~a~~ little work is done so far in South Asia. Similarly in Pakistan, the scope of research ~~on~~ 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 (Nomman and Schmitz, 2011; Hussain and Mudasser, 2007; Hanif et al., 2010; Ashfaq et al., 2011). None of the studies considered farmers' ~~perceptions and their adaptive behavior which is imperative to understand climate change adaptation in agriculture because farmers are the primary decision makers and stakeholders in the agriculture sector.~~ perspective of climate change adaptation~~perceptions~~. ~~The choice of adaptation methods by farmers depends on various social, economic and environmental factors (Deressa, 2007; Brayan et al., 2013). The exact knowledge of these factors may assist policy to enhance the adaptation in agriculture by realizing these factors and investing in farmer-friendly measures for the improvement of the agricultural sector (Deressa, 2007).~~ Hence, this study was designed to fill the existing research gap ~~prevailing~~ in Pakistan with respect to climate change adaptation in the agriculture sector.

This study mainly seeks to answer ~~the~~ two research questions. ~~, i.e.~~ First we will look, how do farmers perceive long-~~-~~term changes in local ~~surrounding~~ climate? Second we will analyze, ~~and~~ how do ~~they~~ 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 findings of this study may bridge the gap of knowledge regarding adaptation of the agriculture sector to climate change in Pakistan and may provide a guide to policymakers in designing effective adaptation policies.~~ 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 section 5 we conclude ~~presenting we conclude~~ our results ~~and present~~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 between 30°00'N~~-31 oN~~ latitudes and 70°00'E ~~72 oE~~ longitudes in the semi~~-~~arid lowlands zone (Wikipedia 2014). Punjab is the most populous and second largest province of Pakistan. It is a fertile agricultural region based on an extensive irrigation network and playing a leading role in the development of the economy (Abid et al., 2011b). The p~~P~~rovince accounts for 56.2 % of the total cultivated area, a 53 % share of the total agricultural gross domestic product and 74 % share towards the total cereal production in the country (PBS, 2011; Badar et. al., 2007). ~~Fig. 2Figure 1~~Figure 1 shows the map of study areas located in Punjab province.

The mean annual minimum temperature in Punjab ranges from 16.3~~-~~ ^{o}C to 18.2~~-~~ ^{o}C over the period 1970-2001. Mean annual maximum temperature in Punjab ranges from 29.3~~-~~ ^{o} C to 31.9~~-~~ ^{o} 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 respectively (Mohammad, 2005).

Based on Pakistan agricultural research council maps (PARC, 2014), the Punjab province can be divided into four major and eleven sub agro-ecological zones based on climate, agricultural production, and aridity. Study districts come from three of the main agro-ecological zones. Study sites in the district Rahim Yar Khan are located in cotton and Cholistan sub-zones where average rainfall ranges from 72.8 to 462.5 millimeters annually. The ~~2nd~~second study district, Toba Tek Singh is located in the central mixed zone, which receives average rainfall ranging between 219.5 and 718 millimeters annually. The third district Gujrat is partially located in both rain-fed and rice zones~~-jointly in high rainfall and rice zone-~~ which receive~~s~~ 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, ~~the~~ according to our study, the average land holding size ~~(in acres)~~ varies ~~to some extent~~ between ~~in district~~the districts Rahim Yar Khan (18), Toba Tek Singh (14), and Gujrat (16). ~~A l~~Little variation is ~~also~~ found ~~in~~for average household size (9-10) and years of schooling (8-9) in all three districts. In terms of agricultural~~e as main source of~~ income shares, ~~all three regions~~ relatively high values are found for the districts of Rahim Yar Khan (85 %)~~,~~ and Toba

Tek Singh (79 %) but a substantially lower value forand Gujrat (26 %)— are different.

2.2. SSampling and data collection

To investigate the farm level perceptions of climate change and associated choices of adaptation methods to climate change in Punjab, our study was conducted in three districts of Punjab, Pakistan. tThe selection of study districts took into account different agro-ecological zones (AEZs), cropping patterns, irrigation source networks, and climate. The study districts are selected from a range of AEZs including irrigated plains,; rain-fed regions and marginal lands.Particularly, –Sstudy sites in the district Rahim Yar Khan are located mainly in irrigated plains (Zone A) and partially in marginal lands (Zone D). The study district Toba Tek Singh is located in irrigated plains (Zone A). The study district Gujrat is located in thea 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 Pakistan province of Punjab was selected as overall study area. In the second stage, three districts were selected from three agro-ecological zones based on the agriculture share to 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, a criterion was developed for the selection of union councils. According to this criterion, the union councils with the urban population were excluded from the list, and 20 % of the union councils were selected from the rest as a sample using a random sampling method.we choose 10-13 union councils from each district depending on number of union councils located in each district. 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, 6 farmers were randomly selected from each village. Table 1 Table 2 depicts the numbers of farmers interviewed from the study areas.

The survey was conducted between March 2014 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 cropping year 2012-13 for both which includes the *Rabi* (winter) season 2012-13 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 ~~start of the~~ study, a pretesting of the questionnaire was ~~done~~performed to ~~make it realistic based on local information~~avoid missing of any important information. The enumerators ~~were given short-term in~~received field training about the study objectives and farm household survey.

~~1.1.~~2.3. Dependent and independent variables

Several a~~A~~gricultural ~~A~~adaptation measures ~~is a way to avoid~~can reduce losses due to increasing temperature and decreasing precipitation (Hassan and Nhemachena, 2008). In this study, a binary logistic model was use~~-~~d to examine the factors influencing the choice of different adaptation measures applied by the ~~sample~~ farm households in the study area. ~~In order to decide~~The decision to adapt ~~to changes in climate,~~ requires that farm households ~~must first~~ recognize ~~and their concerns about climate change and perceive~~ local changes in long-term climate such as temperature and rainfall patterns ~~in their area~~ (Bryan et al., 2013).

Following ~~the~~ previous studies ~~of~~ by Kato et al. (2011) and Bryan et al. (2013), we assume that farm households will ~~choose to adopt certain~~ adapt~~ation measures~~ ~~adapt to climate variability~~ only if they perceive a reduction in the risk~~s~~ to crop production ~~and~~ or an increase in expected net farm benefits ~~associated with adoption use of a particular adaptation measure to climate variability~~. Consider a latent variable (Y_{ij}*) which is equal to expected benefits from the adoption of certain adaptation measures ~~and depends on X_k=~~:

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

~~(1)~~

In this equation, Y_{ij}* is a latent binary variable with subscript i depicting the household who adapted to climate variability and j~~i~~ ~~showing~~depicting eight different adaptation measures ~~(varies from one to eight).~~, ~~and~~ X_k represents the vector of exogenous explanatory variables that influence the farmers' choice of adopting particular adaptation measures and k in the subscript shows the specific explanatory variable (varies from zero to 14). ~~Here~~ 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:

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

~~(2)~~

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

Hence, we ~~may~~ can interpret equation (2) in terms of the observed binary variable (Y_{ij}) as:

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

~~(3)~~

Where G (.) 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 regressors (independent variables) on the binary dependent variable (regressand) 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 tells that an independent variable X_k increases the likelihood that Y_{ij}= 1 (which is adoption of particular adaptation measure in our case). But this coefficient cannot explain how much the probability of household i to adopt particular adaptation measure (Y_{ij}=1) will change when we change X_k, i.e. the coefficient (β_k) ~~reveals nothing~~does not show ~~about~~ the magnitude of the effect of a change in explanatory variable X_k on Pr (Y_{ij}~~i~~=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 dependent variable, i.e. Pr (Y_{ij}~~i~~=~~-~~1). Derivation of marginal effects is discussed in detail in appendix A. The final equation of the marginal effect (y_{ij}') after derivation ~~will be as~~becomes:

~~$$y_i' = \Pr(Y_i = 1)\cdot\left(1 - \Pr(Y_i = 1)\right)\beta_k \qquad (4)$$~~

$$y_{ij}' = \Pr(Y_{ij} = 1)\cdot(1 - \Pr(Y_{ij} = 1))\beta_k \qquad (4)$$

~~(4)~~

Another ~~means~~ alternative to interpret the results of a logistic regression ~~in a more simple and accurate way~~ is to use ~~the~~ partial ~~-~~elasticiti~~y~~es which measure~~s~~ the percentage ~~point~~ change in ~~the~~ probability of the ~~regressand or~~ dependent variable (adoption of certain adaptation measure to climate variability) due to a 1 ~~%~~ percent increase in the explanatory variable X_k (see appendix ~~-(~~A~~)~~ for further detail). We may interpret the partial ~~-~~elasticity of the logit model calculated at mean as:

~~$$\eta_Y(\overline{X_k}) = \beta_k \overline{X_k} \Pr(Y_i = 1)\left(1 - \Pr(Y_i = 1)\right) \qquad (5)$$~~

$$\eta_Y(\overline{X_k}) = \beta_k \overline{X_k} \Pr(Y_{ij} = 1)\cdot(1 - \Pr(Y_{ij} = 1)) \qquad (5)$$

~~(5)~~

~~1.2.~~2.5. D~~2.3 5 D~~escription 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 ~~used in this study~~ include household characteristics (e.g. farming experience of household head, household head's education, ~~, ,~~ size of household, ~~tube-well~~tube well ownership, land holding and tenancy status of farm households), ~~;~~ institutional factors (e.g. access to credit, market information, weather forecasting information, information on water deliveries, agricultural extension services), and ~~agro-ecological factors~~dummies for agro-ecological zones. ~~In this study, i~~Instead of using agro-ecological factors (e.g. temperature and rainfall) and cultural traits in different regions directly, we used dummy variables for agro-ecological and cultural ~~settingssettingszones,~~ given the absence of variability in temperature and rainfall for households in the same district.

Prior to ~~the start of~~ the survey, a multinomial logit (MNL) modeling approach was proposed for this study. ~~based on a literature review which shows that~~B~~b~~ecause most of the previous studies ~~focusing on~~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 adaptation measure. ~~But~~ However, in ~~our~~ the course of this study, ~~it was~~we frequently found that ~~sometimes~~ farm households ~~involved in adopting~~ adopted more than one adaptation measure simultaneously. This behavior ~~which make impossible to use~~made the use of the MNL approach ~~for this study~~ inappropriate. ~~even after~~ A possible remedy would be to combin~~ing~~e similar measures into single categories (Bryan et al., 2013). ~~Furthermore~~However, such grouping ~~of similar measures~~ into self-defined ~~groups or~~ categories may lead to ~~the possibility of~~ misinterpretation ~~of key adaptation measures being adopted by survey farm households~~ (Bryan et al., 2013). Furthermore, the set of explanatory variables influencing the farmers' decision ~~of adaptation were~~ was also expected to be different for different adaptation measures. Therefore, we ~~preferred to~~ employed the logistic regression technique to examine the factors that affect the choice of ~~farm households' choice to~~households ~~to implement certain~~ adaptation measures. Table 2~~–~~ ~~Table 1~~ shows the description and expected signs of explanatory variables used in this study.

~~1.3.~~2.6. ~~2.4~~ ~~6~~ Hypothesis testing for model significance

~~Before running a complete analysis~~W~~, w~~e tested all of our models ~~to check~~ for significance and accuracy ~~for~~ of predictions. There are ~~many~~ 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 and Lameshow, 2004). Higher percentages indicate a better fit of the model. The results of the classification table test (Table 3~~Table 1Table 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 : 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. equation (1), fits significantly better than the model with just an intercept (i.e. an intercept-only model):

$$Y_i^* = \alpha \qquad (6)$$

(6)

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

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 chi-squared with 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 chi-square 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 thee 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, Ffarmers' perception of long term or short term changes in climate is a crucial pre-indicator in the adaptation process (Adger et al., 2009) and plays an important role

~~in shaping farmers' behavior (Adger et al., 2009). Various studies have explored the importance of perceptions of risk and the cognitive process of primary decision makers for the adoption of different adaptation decisions (Frank et al., 2011, Grothmann and Patt, 2005)~~. ~~In this study, we defined climate change as observed or perceived changes in the local environment over the period of 10-20 years or more in terms of occurrence of extreme environmental events such as droughts, floods, extreme high or low temperatures, human or animal diseases; perceived changes in average summer and winter temperature; changes in rainfall and growing season length (Bryan et al., 2013).~~ Hence, ~~R~~respondents were asked how they perceive long-term changes in climate indicators in their area.

The study results (~~Fig. 3~~Figure 2a~~Figure 2a~~) indicate that ~~majority~~ large number of farmers perceived a slight increase in temperature for both summer (56.9 %) and winter~~s~~ seasons (39.3 %). ~~About~~ In perceiving the precipitation patterns~~trends~~, 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. 3~~Figure 2b~~Figure 2b~~). The majority of the surveyed farmers (52.2 %) perceived an increase in growing season length for the *Rabi* (winter) season, while 57.1 % of the farmers observed no change in growing season length for the *Kharif* (summer) season (Figure 2c~~Figure 2Fig. 3bc~~).

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

~~1.4.~~3.2. Farm-~~-~~level adaptation process

In our study, we also analyzed the whole adaptation process across all three study districts (~~Fig.~~ Figure 4).~~4).~~ 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 maximum perception in district Gujrat (86 %) and lowest perception in Rahim Yar Khan (73 ~~5~~%). In the second~~2nd~~ stage (intention stage), overall ~~73~~75 % of the farmers show their intentions to adapt to climate change with highest intentions in district Gujrat (85 %) and lowest intentions 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~~70 %) and lowest adaptation 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 ~~an 8.2%~~a drop from 81 % to 7~~3~~5 % ~~reduction~~ was observed in responses while from intention stage to adaptation stage, responses of farm households were ~~reduced by 22.6%~~dropped from 7~~1~~5 % to 58% on average. In the same way, moving from perception stage to adaptation stage, ~~Overall decrease in responses~~farmers' responses were dropped from 81 % to 58 %. ~~from perception to adaptation stage~~. ~~was 29%.~~ 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~~(4.3)~~.

~~1.5.~~3.3. Farm-~~-~~level adaptation strategies and constraints

Farmers who observed ~~long term~~ variability in the climate over the period of 10 to 20 year were further asked to describe the farm level adaptation measures undertaken ~~by them~~ 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 Figure 5 ~~Fig. 5Figure 5~~, the most common adaptation measures ~~the most commonly adopted adaptation measures~~ were: ~~the~~ changing crop varieties (32.20 %), changing planting dates (28.40 %), planting trees (25.30 %) and changing fertilizers (18.70 %) followed by changing crop types (10.20 %), increasing irrigation (9.~~78~~80 %), soil conservation (9 %), crop diversification (7.56%), migration to urban areas 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 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 (Figure 5~~Figure 5Fig. 5~~). In the Gujrat district, major adaptation measures adopted by farmers were: use of different~~-~~ crop varieties (39 %), changing planting dates (36.70 %), planting shade~~d~~ trees (31.30 %) and changing fertilizers (24 %). The main reason for~~of~~

changing crop variety, planting dates and plantation of shaded trees may be due to more dependence of farming on rain and groundwater for cultivation of crops in the Gujrat district. That's 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~~d~~ trees (17.30 %) were the primary adaptation measures. In Rahim Yar Khan, farmers mainly used changing planting dates (31.30 %), planting shaded trees (27.30 %), changing crop variety (22 %), changing fertilizer (20 %) and changing crop types (18 %) as the adaptation measures in a changing climate (Figure 5~~Figure 5Fig. 5~~).

Moreover, we identified a number of constraints faced by the farmers who perceived long-term changes in climate and ~~were~~ 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 ~~(Fig. 1Figure 8)~~. The major constraints identified by the majority of the respondents (Figure 6)~~Fig. 6Figure 6)~~ were ~~the~~ lack of information (44 %) and lack of money (22 %) followed by resource constraint (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 case of extreme weather events, including high rainfall, water stress at sowing stage, extreme high temperature or extreme low temperature which are frequently mentioned as indicators of climate change. Farmers showed their intention to adopt particular adaptation measure in 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~~of~~ adaptation, even if they plan to adapt to climate variability. Use of farm credit in the study sites is limited, ~~besides~~ despite access to micro-credit facilities available at the town level. High interest rates on credits ~~may be a~~are one of the reasons for ~~less~~ little ~~interest~~ attraction of credit institutions ~~of for~~to farmers ~~in towards formal credit institutions~~. Less access to or availability of resources at farm level constrains the capability ~~in~~ of adapting to climate change. ~~Here resources mean p~~Physical resources ~~which~~ 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 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.

3.4. ~~43.4~~ Adaptation to climate variability across regions and different farm characteristics

From the results of the adaptation process explained above in section ~~(4.3)~~3.2 and Figure~~Figure 9)Fig. (1)~~, we can observe that farm level adaptation processes (perceptions, intentions and adaptation) are influenced by various factors. These~~s~~ adaptation measures can be further explored based on different characteristics of farm households or their location. Hence, we assume that perceptions, intentions ~~to adapt~~ and final decisions of adapting ~~adaptation~~ to climate change all differ ~~both~~ in term of extent ~~and decision~~ 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 having no formal education; farmers having 1 to 10 years of schooling; and farmers having more than 10 years of schooling (Figure 7)~~(Fig. 7Figure 7)~~. In terms of farming experience, we again divided farmers into three categories, i.e. farmers having less than 10 years of experience in farming; farmers having 10-20 years of farming experience, and farmers having more than 20 years of experience.

From the results shown in Figure 7~~Fig. 7Figure 7~~, it can be observed that moving from a low education level 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 ~~perceived (44.2%) more compared to the 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 %) 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 ~~are having~~had more than 10 years of schooling, and 18.2 % of the farmers had education between 1 and 10 years. Adaptation was lowest in 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 Rahim Yar Khan, Toba Tek Singh and Gujrat at district level with little variation (Figure 7)~~(Fig. 7Figure 7)~~.

Analysis of adaptation measures across different categories of farmers based on farming experience is explained in Figure 8~~Fig. 8Figure 8~~. Farmers with more than 20 years of experience were more likely ~~perceived~~ (40.9 %) to perceive ~~in~~ variability in climate than ~~more than~~ farmers having experience between 10-20 years (28.2 %) or farmers having 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 than 20 years of farming experience (38.4 %) have higher intentions to adapt compared to the farmers in the other two groups, i.e. farmers with experience between 10-20 years (26.2 %) and farmers with less than 10 years of experience (10 %). Farmers with more than 20 years of farming experience were the 30 % of the total farmers who adapted to climate change while farmers with experience between 10-20 years (20 %) and farmers with less than 10 years of experience (7.8 %) adapted less. Figure 8 ~~Fig. 8Figure 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

~~From the discussion, we can conclude that the higher the level or education or farming experience, the higher will be the probability of adaptation to climate change.~~

~~43.5 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. F~~and f~~inally partial-elasticity calculations to elaborate the percentage impact of various factors on the probability of different adaptation measures are described in~~–~~ 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. ~~43.5.1~~ 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 increase the probability of choosing changing crop varieties, changing plantation dates and changing fertilizer as adaptation measures. Elasticity calculations in Table 6~~–~~ show that 1 % increase in the years of experience~~s~~ increases the probability of adopting changing crop variety (0.14 %), changing planting dates (0.15 %) and changing fertilizer (0.11 %) as adaptation measures respectively. The results of the study are in accordance with those from ~~with the results of the studies by~~ 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 higher farming experience are likely to be more aware of past climate events and may judge better to adapt their farming to extreme weather events.

3.5.2. ~~43.5.2~~ 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) ~~(Norris and Batie, 1987)~~. 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 of the household head (Table 4)~~-~~. Results of 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~~2~~%), changing crop variety (0.09~~4~~ %), changing planting dates (0.17 ~~3~~%), plantation of shaded trees (0.08~~5~~ %), soil conservation (0.08~~2~~ %), changing fertilizer (0.15 %) and irrigation (0.09 ~~1~~%) as adaptation measures to climate variability. Various studies (Bryan et al., 2013; Deressa et al., 2009 and 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 ~~higher~~ 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. ~~43.5.3~~ Household size

A positive coefficient of household size indicates a positive relationship between household size and probability of adaptation. For instance, an increase in one member of the average household ~~a 1% increase in the size of household~~ would lead to a ~~0.173~~0.20 % increase in the likelihood of plantation of shaded trees and 0.~~0~~47 ~~45~~% increase in choice of soil conservation as adaptation measure. Findings of the studies of Croppenstedt et al. (2003) and Deressa et al.

(2009) also support~~s~~ our findings of a positive relationship between household size and adoption of agricultural technology or adaptation to climate change.

3.5.4. ~~4~~3.5.4 Land area

Land area represents the total land area ~~holds~~ held by a farm household and may be taken as a proxy for farm household wealth. 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~~1~~ % and 0.06 % respectively (Table 6) ~~(Table 6)~~.

3.5.5. ~~4~~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)~~owner operator farmers~~. ~~As~~ 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 ~~self-operating farmers (owners)~~owners as 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.~~self-operating farmers (owners).~~

3.5.6. ~~4~~3.5.6 ~~Tube-well~~Tube well ownership

~~Tube-well~~Tube well ownership indicates adequate supply of ground water for crops in time of need. The ownership of ~~tube-well~~tube well is positively associated with~~to~~ the majority of the adaptation measures, even though the coefficients are insignificant. Moreover, ownership of ~~tube-well~~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 having a ~~tube-well~~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 farm level in response to variability in climate.

3.5.7. 43.5.7 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. A 1 % increase in the distance of the farm from nearest local market would result in a decrease of 0.05 3% in the probability of the changing crop type (Table 6). –

3.5.8. 43.5.8 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 type and increased irrigation and negatively related to the changing crop type, changing planting dates, plantation of shaded trees, soil conservation, changing fertilizer and crop diversification, although not significantly.

3.5.9. 43.5.9 Access to information on water deliveries

Access to information onf water deliveries has positive but insignificant impact on most of the adaptation measures except changing planting dates (Table 4). The access to information on water deliveries increases the likelihood of changing planting dates by 11.73 % (Table 5)Table 5). We can conclude that farmers who have more access to information on water deliveries are more likely to adjust the planting dates according to water availability.

3.5.10. 43.5.10 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, plantation of shaded trees, soil conservation, changing fertilizer, irrigation and crop diversification as adaptation methods. Results in Table 5– –show that access to information on seasonal and daily weather increases the probability of plantation of shaded 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 increaseincreases the likelihood of adaptation to climate change.

3.5.11. ~~43.5.11~~ Extension of crop and livestock production

Agricultural extension is an ongoing process and ~~may be of various kinds. It~~ 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).

Results in Table 4~~–~~ indicate that the extension of crop production is significantly and positively related to changing crop variety. On the other hand, it is ~~– and~~ significantly and negatively related to the probability of changing crop type which~~. The insignificant relation~~ may be due to the reason that farmers get poor information from~~over~~ crop production and adaptation to climate change, or the quality of extension 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~~among~~ extension and adaptation measures. These results support the farmers' complaint about lack of updated information on adaptation to climate change by the extension department.

3.5.12. ~~43.5.12~~ Access to market information

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

3.5.13. ~~43.5.13~~ Irrigated plains mixed cropping zone (base rain-fed zone)

Farmers living in different agro-ecological zones used different adaptation measures. For example, the farming in mixed cropping zones leads to an increase in the likelihood of changing crop variety (11.21 %), changing planting dates (24.47 %), planting 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 cropping zones adapt differently based on cropping patterns and needs.

3.5.14. ~~43.5.14~~ 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 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 plantation dates as adaptation methods by 28.85 % and 9.69 % respectively compared to the farming in other zones.

3.6. ~~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 farm level (~~Fig. 1~~Figure~~Figure~~ 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 (socio-economic) and external ~~factors~~ (e.g. environmental or institutional) factors~~)~~. ~~After perceiving climate change, in~~ In the second stage, farmers show 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 section ~~(~~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)~~(Table 4Table 4Table 4)~~. While the farmers' decisions of not adapting to climate variability ~~not to adapt~~ may be explained by various constraints ~~mentioned~~elaborated by farmers, –who do not ~~choose~~adapted ~~not to adapt~~ even having inten~~s~~tions (Figure 2)~~Fig. 3Figure 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~~of variables with~~ interdependent variables (perceptions, intentions or adaptations), respectively, while dotted lines represent a weak link, and full lines show~~s~~ a significant relationship.

3.7. ~~4~~3.~~6~~ ~~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 (Figure 10) ~~(Fig. 9Figure)~~. From the results, it can be observed that elasticity scores range from -0.01 to 0.20 except ~~one exception~~ for elasticity scores (0.30–0.40) of weather information variable in the planting trees model. Elasticity of farming experiences is higher for farmers in the district Rahim Yar Khan for most of the adaptation methods followed by farmers in district Toba Tek Singh and Gujrat respectively. The highest elasticity of farming experience was observed in case of adaptation measures changing crop varieties (0.15) and changing planting dates (0.16) both forin Rahim Yar Khan respectively 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 highest score (0.18) was obtained for changing planting dates in Rahim Yar Khan and a. While 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 district Rahim Yar Khan.

Elasticity calculations for household size show the highest elasticity in the case of planting 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 case of the variable of total land holding, the highest coefficient was observed for changing crop variety in district Rahim Yar Khan (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 land holding on adoption of these measures. Elasticity coefficients for tenancy status variable were higher for district Rahim Yar Khan followed by district Toba Tek Singh and Gujrat.

4. 64. 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 environmental disasters likeextreme events including –floods and, droughts and changing rainfall patternsless uncertain rains (Asif 2013). Being mostlyseverely dependent on natural water resources, agriculture in Pakistan is most likely to be affected byparticularly vulnerable to ongoing further climate changeAgriculture is more likely to be affected by climate change due to its direct connection to climate. Hence, the suitable adaptation measures of agriculture to climate change is are neededimportant, especially at micro level. This study shows that farmers do perceive and are concerned about changes in climate and its effects on their farming the important findings about theuses novel farm-level data from three distinct provincesagro-ecological zones in Pakistan to analyze farmers' awareness and their adaptive capacities and measures to changes in climate. The majority of the farmers perceived variability in mean temperature and rainfall for both summer and winter season over the last 10 to 20 years.

This sStudy also showsreveals existing andreal and perceived and existing constraints infor farm--level adaptation to climate changes which need to be addressed. Farmers are more likely to perceive climate change but less likely to intend or to adapt to climate change. Farmers are adapting their farming to avoid climate change vulnerabilities. Most of the farmers choose changing crop varieties, changing planting dates, changing fertilizers and planting shaded trees as adaptation measures to climate change. This study also examined the important factors affecting the likelihood of different adaptation measures in a changing climate. The study revealed that the household characteristics are positively associated with adoption of adaptation measures to climate change. It was found that farmers with higher education level more likely adapt to climate change compared to farmers with less education. Similarly farming experience, farm household size, land area and tube-well ownerships also significantly increases the probability of adaptation to climate change.

On the other hand, tenants more likely adapt compared to self-operating farmers which may be due to the fact that tenants have more burden to keep their farm revenue above the total cost. Moreover, farmers located near to the local market are more likely to change their crops as adaptation measures that may be due to the easy access to new information on high yielding varieties and crops. This study also revealed that institutional factors such as extension on crop production, access to information on climate, and access to market information and water deliveries enhance adaptation to climate change. This study also revealed the importance of education and farming experience on perceptions, intentions and adaptation to climate change which increase with increase in the farming experience and education level.

However, farmers' decisions to adapt to climate change are constrained by various factors which include mainly lack of information, lack of money, resource constraint and less irrigation water. The findings of the study depict that most of the constraints faced by farmersMost the constraints prevailed are of an institutional in nature and can be covered with improving the institutional sservices in term of access, use and viability etup for climate adaptation. Furthermore, this study revealedshows the importance of different kindstypes 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. But stillHowever, the services currently provided at farm level are not sufficient to support thean effective adaptation process. Hence there is dare need for collaborations at different levels of the adaptation process. This study also reveals the necessity ofThese collaborations may include public-private partnerships or integration at horizontal and vertical levels of public and private organizations.to improve this social and institutional structure to enhance the farm level adaptation in agriculture. Policies are aiming for the betterment of agriculture and need to focus more on the distribution of updated information on improved agricultural technologies and climate change adaptation to benefit the farmers to adapt their farming in a changing climate. This study also shows that farmers in different agro-ecological zones are adoptingprefer different adaptation measures compared to other zones. Hence, itThis diversity shows confirms the need of for research at local levels, i.e. on in different agro-ecological zones, before to designdeveloping future efficient and effective adaptation policies strategies especially for the agriculture sector.

Moreover, only 58% of the farmers in Punjab adopted at least one adaptation measures but only 30% of farmers adapted two or more adaptation measuresWeThe studyStudy also showss that historical adaptation measures at farm level is not ofdo generally not include an advanced management technologies level and onlybut are limited to adopting certainsimple measures, particularly . Most of the adaptation measures adopted by farmers are limited to changing crops or crop varieties. V and very few farmers adopted advanced types of adaptation measures such as soil conservation, crop diversification, etc. 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 focus address more on the enhancement ofbarriers for the adoption of the advanced adaptation measures at farm-level such as providing information and support, introducing climate smart varieties, promoting soil conservation and new adaptation measures based on different agro-ecological zones.

BesidesDespite the need for small-scalelocally specific adaptation of agriculture to climate change, investment and research are also needed at macro-level. Particularly, commodity prices, resource endowments, and environmental impacts depend on regional and international developments but interact with local adaptation measures adaptation measures which ultimately benefit the small-scale agriculture from both ends.

Appendix A: Marginal effect and elasticity calculations

Let us have a logit function (in term of observed variable Y_{ij}~~i~~) already explained in equation (3) in section 2:

$$\Pr(Y_{ij}=1)=Y_{ij}=G(X_k\beta) \qquad \text{(A1)}$$

~~(A1)~~

w~~W~~here G(.) takes the specific binomial distribution (Fernihough 2011).

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

$$\frac{\partial Y_{ij}}{\partial X_k}=\frac{\partial G(X_k\beta)}{\partial X_k}=\frac{\partial G(X_k\beta)}{\partial X_k\beta}\cdot\frac{\partial X_k\beta}{\partial X_k}=G'(X_k\beta).\beta_k=g(X_k\beta)\beta_k \qquad \text{(A2)}$$

~~(A2)~~

As we know that

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

So the derivative of G(Xkβ) with respect to Xkβ by applying quotient rule (Dawkins, 2005), will be followed as:

$$g(X_k\beta)=\frac{\left(1+e^{X_k\beta}\right)\cdot e^{X_k\beta}-e^{X_k\beta}\cdot e^{X_k\beta}}{\left(1+e^{(X_k\beta)}\right)^2}$$

$$=\frac{e^{(X_k\beta)}}{\left(1+e^{X_k\beta}\right)^2} \qquad \text{(A3)}$$

~~(A3)~~

If we put the value of g(Xkβ) from equation (A3) into equation (A2) then it becomes:

$$\frac{\partial Y_{ij}}{\partial X_k}=\frac{e^{(X_k\beta)}}{\left(1+e^{X_k\beta}\right)^2}\cdot\beta_k \qquad \text{(A4)}$$

~~(A4)~~

Usually marginal effects are calculated at mean of explanatory variables ($\overline{X_k}$ ~~Xk~~) so we may replace X_k with mean value of $\overline{X_k}$ ~~Xk~~ (Schmidheiny, 2013):~~.~~

$$= \frac{e^{(\overline{X_k}\beta)}}{1+e^{(\overline{X_k}\beta)}} \cdot \frac{1}{1+e^{(\overline{X_k}\beta)}} \cdot \beta_k$$

$$= \Pr(Y_{ij}=1)\cdot\left(1-\frac{e^{(\overline{X_k}\beta)}}{1+e^{(\overline{X_k}\beta)}}\right)\cdot\beta_k$$

$$= \Pr(Y_{ij}=1)\cdot\left(1-\Pr(Y_{ij}=1)\right)\cdot\beta_k$$

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

$$\eta_Y(X_k) = X_k \cdot \frac{\partial G(X_k\beta)}{\partial X_k} \qquad \text{(A5)}$$

~~(A5)~~

As $\frac{\partial G(X_k\beta)}{\partial X_k}$ is simply the marginal effect of logistic regression (see equation 4) so we may write equation ~~2.6~~A5 as:

$$\eta_Y(X_k) = X_k \cdot \Pr(Y_{ij}=1)\cdot\left(1-\Pr(Y_{ij}=1)\right)\beta_k \qquad \text{(A6)}$$

~~(A6)~~

Moreover we can conclude partial-elasticity X_k times the marginal effect (y_{ij}') ~~of the explanatory variable~~ (Rahji and Fakayode, 2009).

In ~~the~~ a similar way of calculating marginal effects, partial elasticities are also calculated at mean of explanatory variables ($\overline{X_k}$)~~(Xk)~~ so we may write equation (7) as:

$$\eta_Y(\overline{X_k}) = \beta_k \overline{X_k} \Pr(Y_{ij}=1)\left(1-\Pr(Y_{ij}=1)\right) \qquad \text{(A7)}$$

~~(A7)~~

Where $\Pr(Y_{ij}=1) = \frac{e^{(\overline{X_k}\beta)}}{1+e^{(\overline{X_k}\beta)}}$

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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

–Table 2. Description of Explanatory Variables Used in the Model

Explanatory variable	Mean	Std. Deviation	Description	Expected signs
Years of experience in farming	24.37	11.97	Continuous	(+)
Years of education	8.510	4.256	Continuous	(+)
Household size (numbers)	9.664	5.133	Continuous	(+)
Land holding (acres)	16.06	28.53[1]	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 (km)	9.089	7.610	Continuous	(-)
Access to credit	0.096	0.294	Dummy takes the value 1 if have access and 0 otherwise	(+/ -)
Extension on 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 deliveries	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 cropping zone (base rain-fed zone)	0.330	0.472	Dummy takes value 1 if district “Toba Tek Singh” and 0 otherwise	(+/ -)

[1]This large standard deviation is due to presence of large land holders in district Rahim Yar Khan ~~District~~

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

–Table 3~~Table~~ . Hypothesis Testing for Model Significance and Predictive Power

Models	Chi-square (χ2)	df	P-level	-2*log likelihood	AIC	Model [1] correctness (%)	Nagelkerke pseudo R2
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 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

[1] based on the classification table

P-level shows the statistical significance to reject the null hypothesis (Ho)

AIC (Akaike information criterion) ~~is used to~~ measures the relative quality of the statistical mode~~l~~l

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 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 deliveries	-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**
Extension on 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 cropping 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

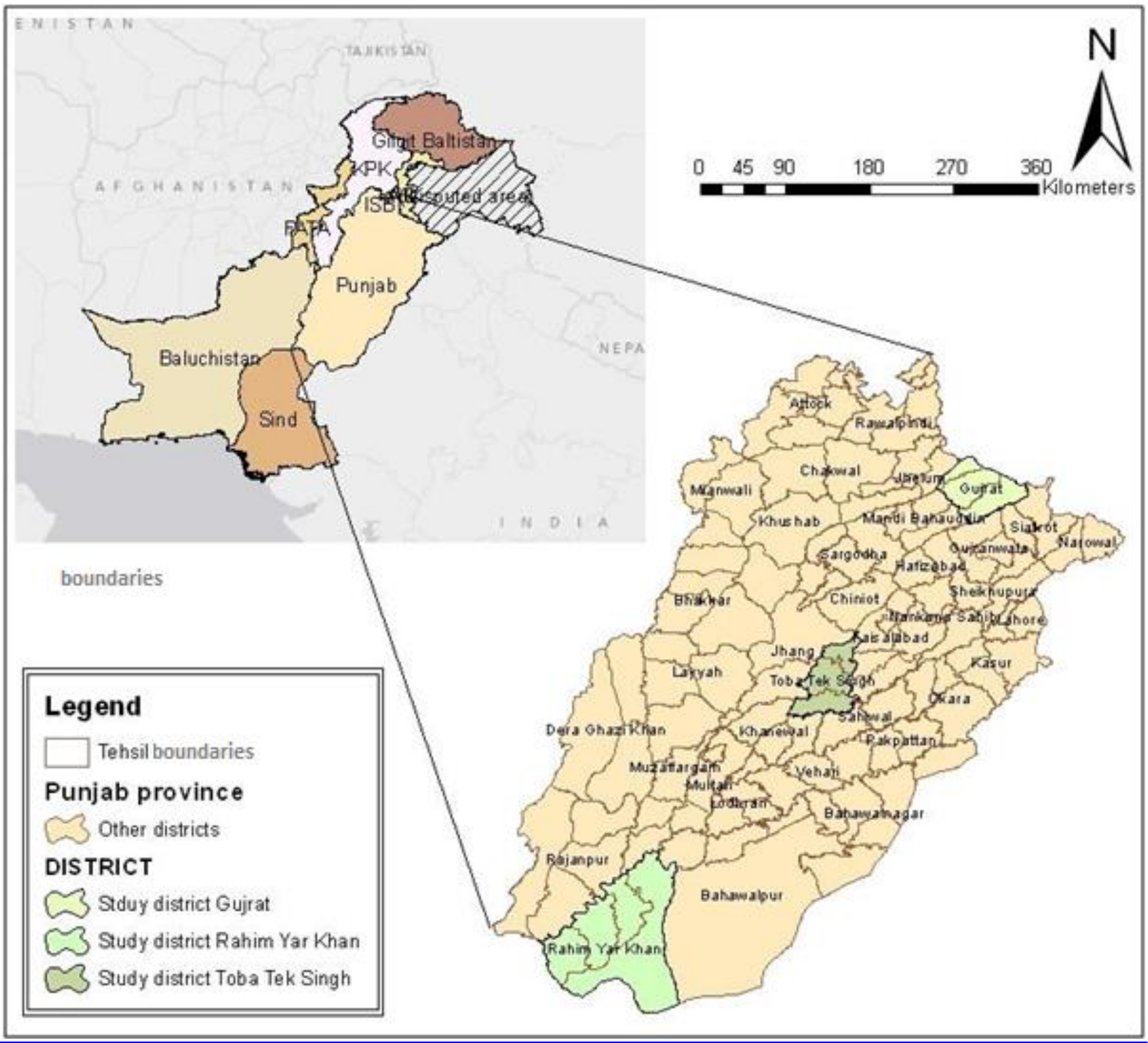
***, **, * Significant at 1 % and, 5 %, and 10% probability level, respectively

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 shaded 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 (numbers)	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 deliveries	-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
Extension on 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 cropping 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

~~Table 4.~~ 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 shaded 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 (numbers)	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 ~~input~~ 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 deliveries	-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
Extension on 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 cropping 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

1 

Gilgit Baltistan
KPK
FATA
ISB
Disputed area
AFGHANISTAN
TAJIKISTAN
NEPA
INDIA
Punjab
Baluchistan
Sind
N
0 45 90 180 270 360
Kilometers
boundaries
Legend
Tehsil boundaries
Punjab province
Other districts
DISTRICT
Stduy district Gujrat
Study district Rahim Yar Khan
Study district Toba Tek Singh
Attock
Rawalpindi
Chakwal
Jhelum
Gujrat
Mianwali
Khushab
Mandi Bahauddin
Sialkot
Narowal
Gujranwala
Sargodha
Hafizabad
Bhakkar
Chiniot
Sheikhupura
Nankana Sahib
Lahore
Faisalabad
Jhang
Kasur
Layyah
Toba Tek Singh
Okara
Sahiwal
Dera Ghazi Khan
Khanewal
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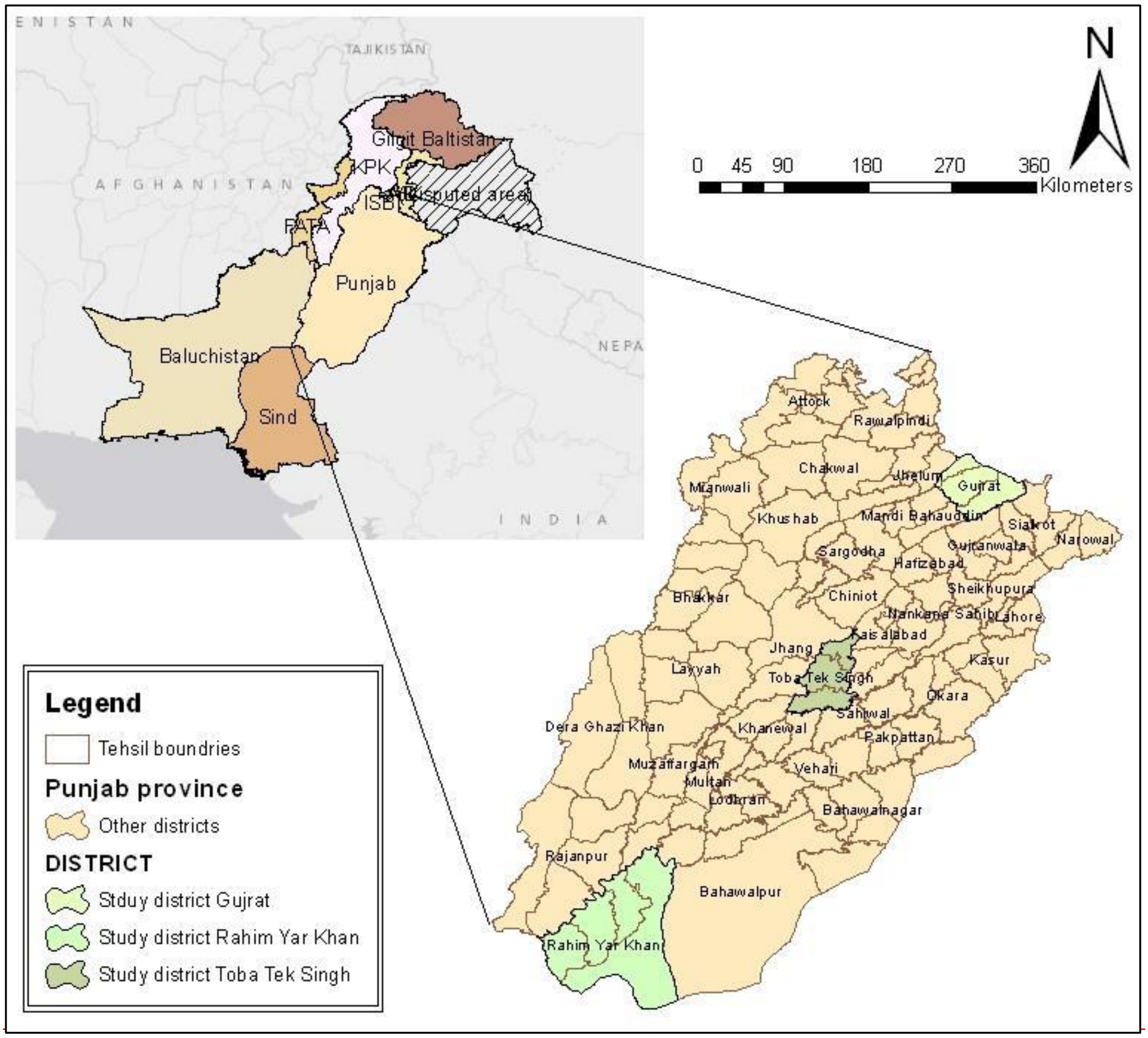
Multan
Vehari
Lodhran
Bahawalnagar
Rajanpur
Bahawalpur
Rahim Yar Khan



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

(a) (b)

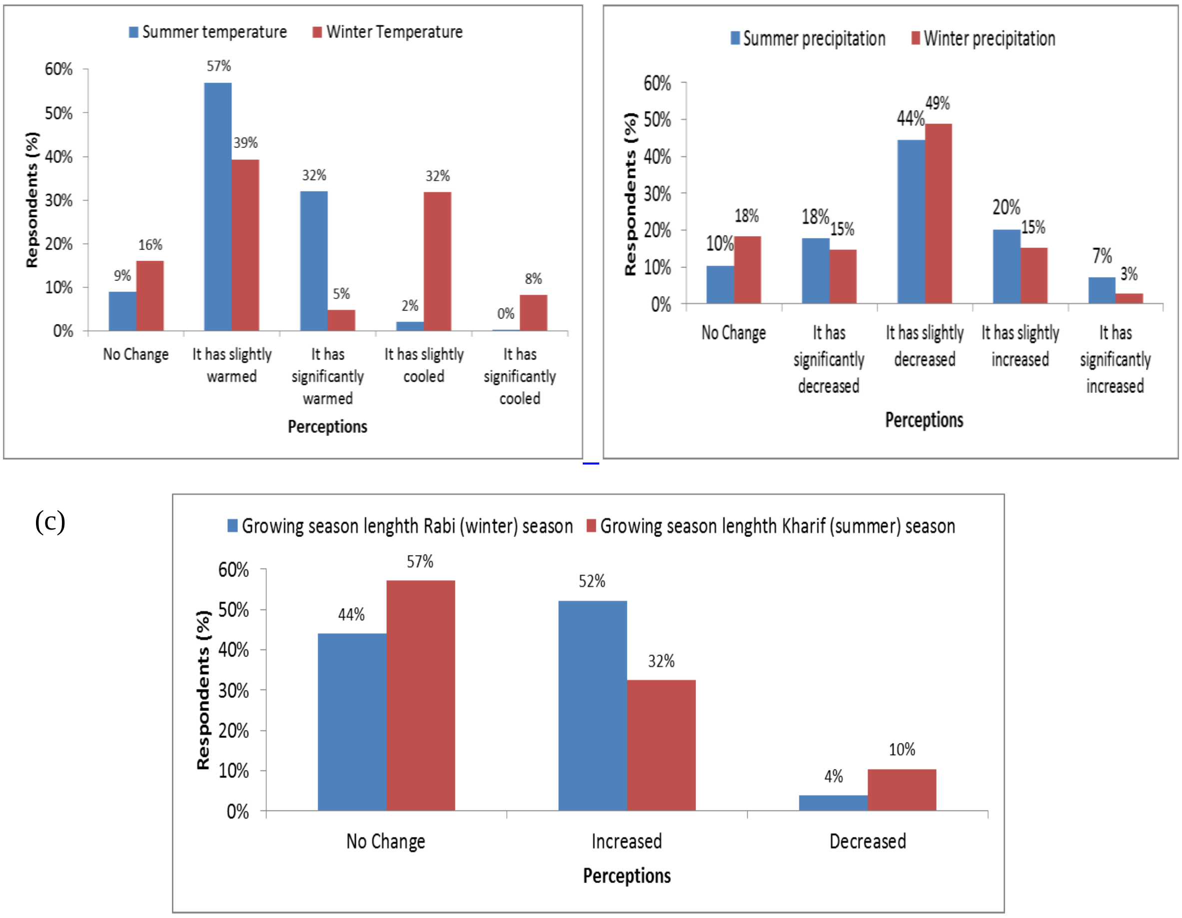
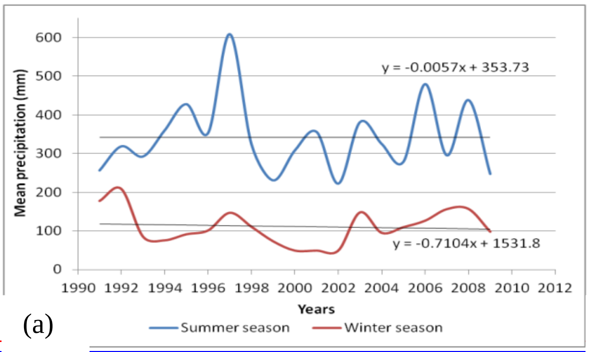
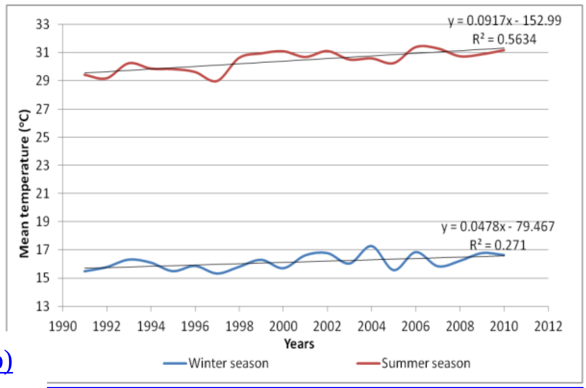


Figure 2~~2~~ (a)-(c). Farmers' perceptions of climate change in study area Punjab Pakistan



(a)



(b)

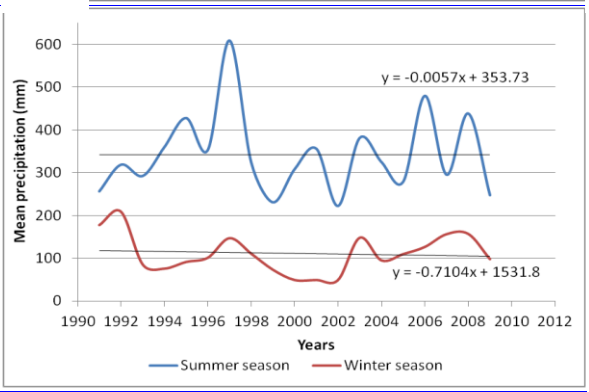
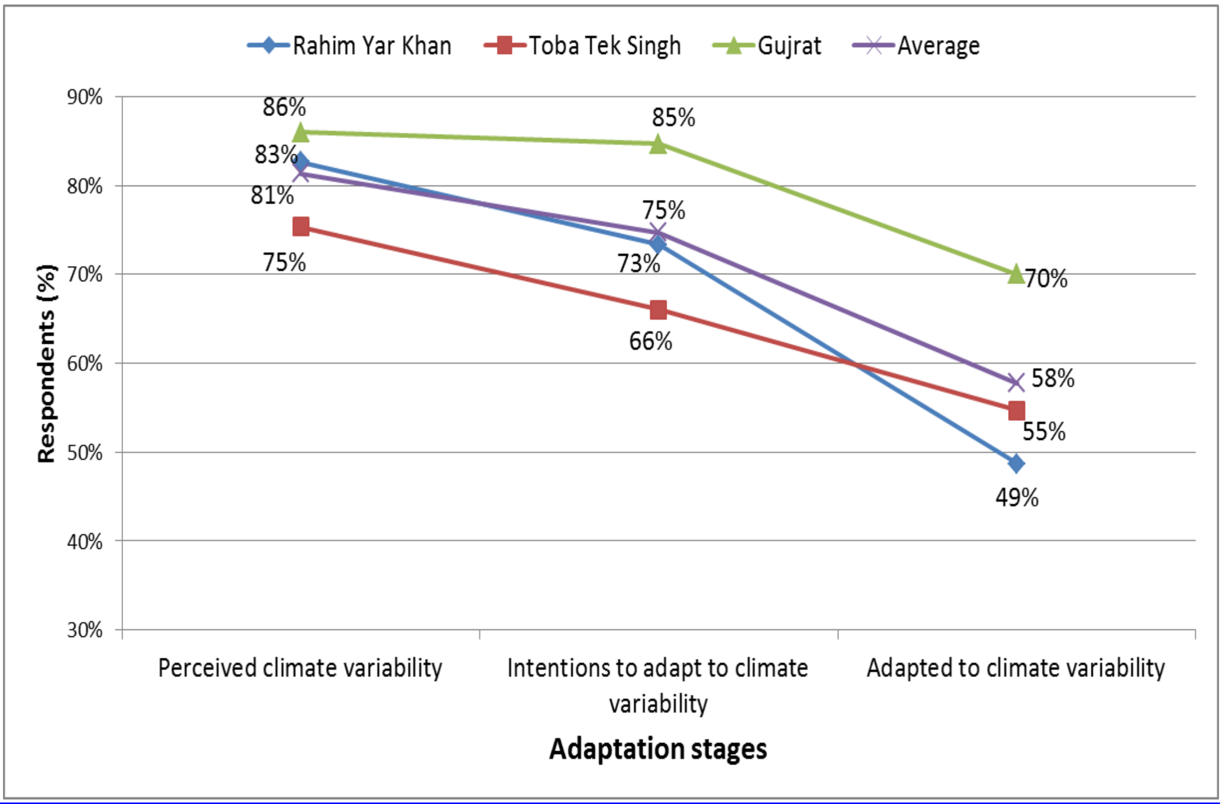


Figure 3~~3~~ (a-b). ~~.~~Mean temperature and precipitation trends in study area over the period of 1990-2010



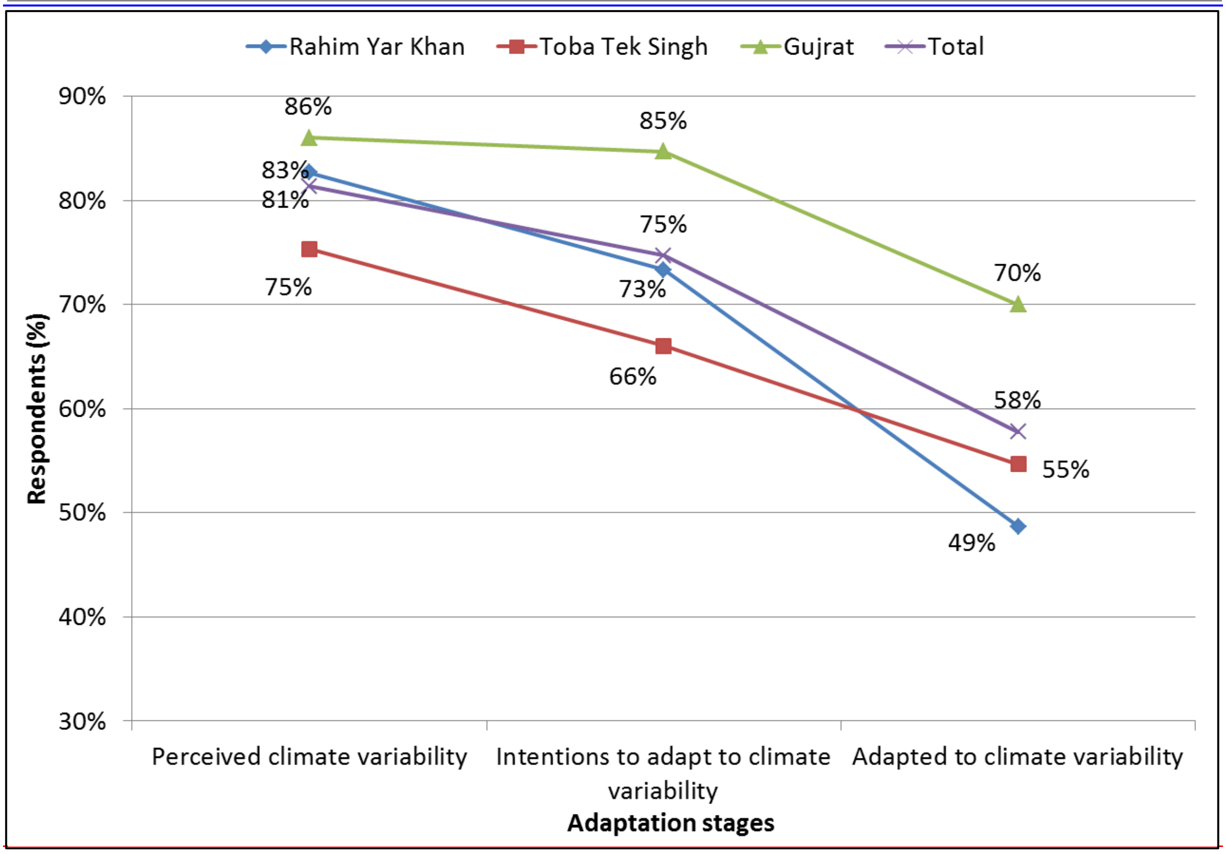
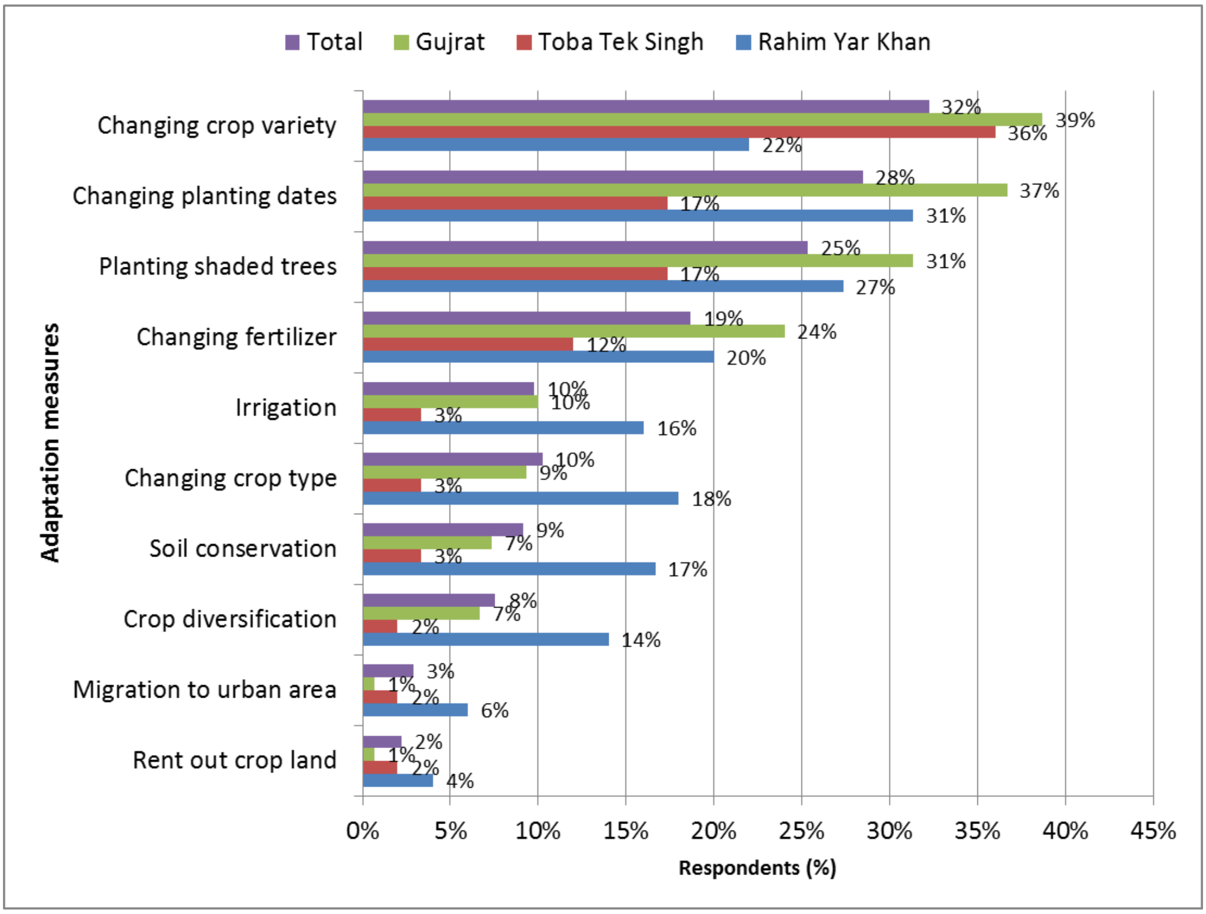
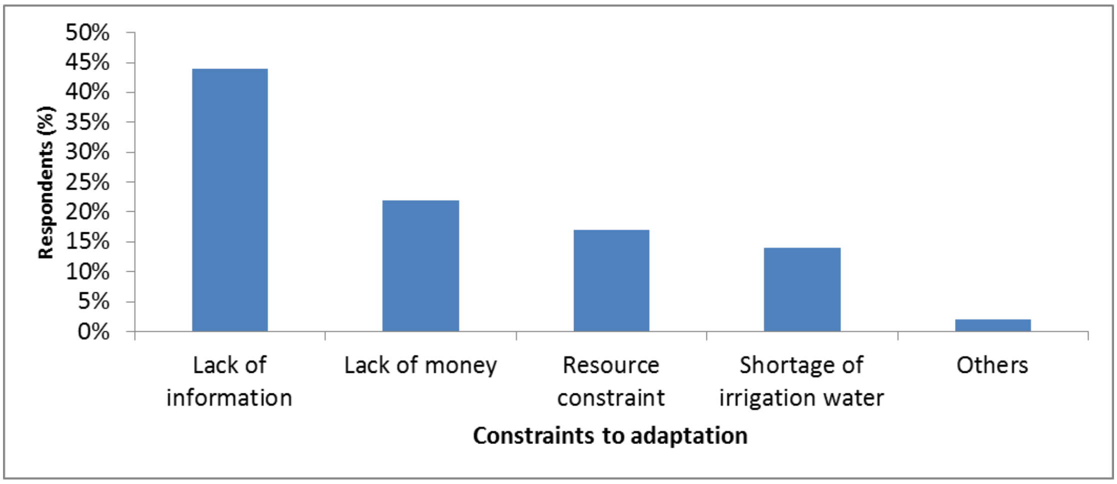


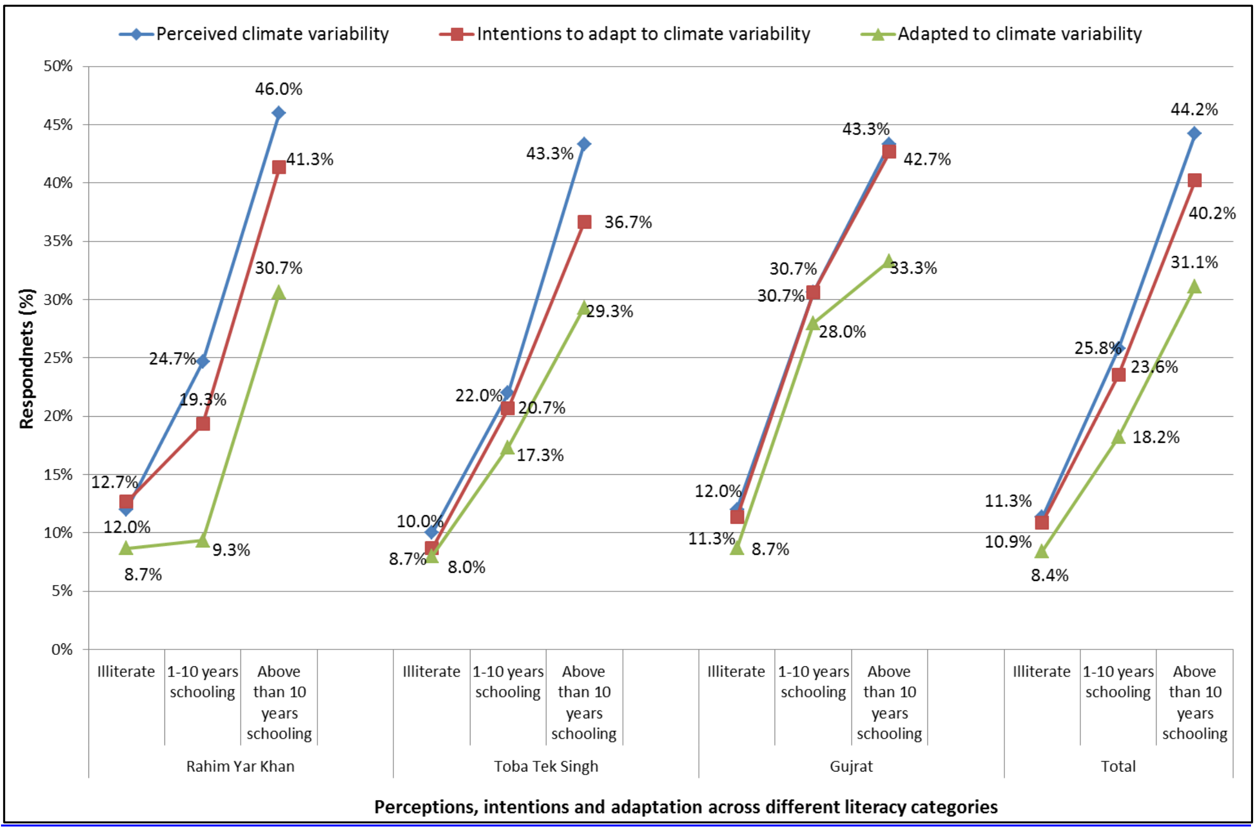
Figure 4. Perceptions, intentions and adaptation to climate change across different study districts



–Figure– 55. Adaptation measures adopted by farmers across three study areas in Punjab, Pakistan



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



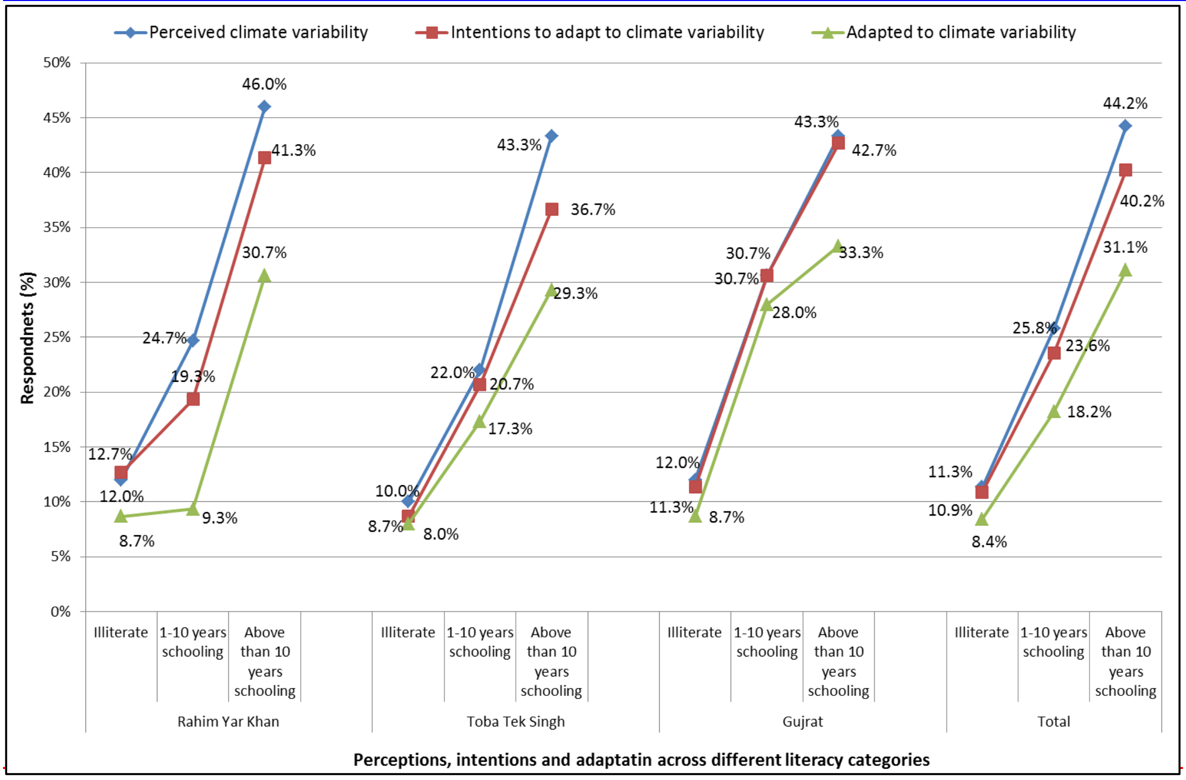


Figure 7. Adaptation to climate variability across different categories of farmers based on education level

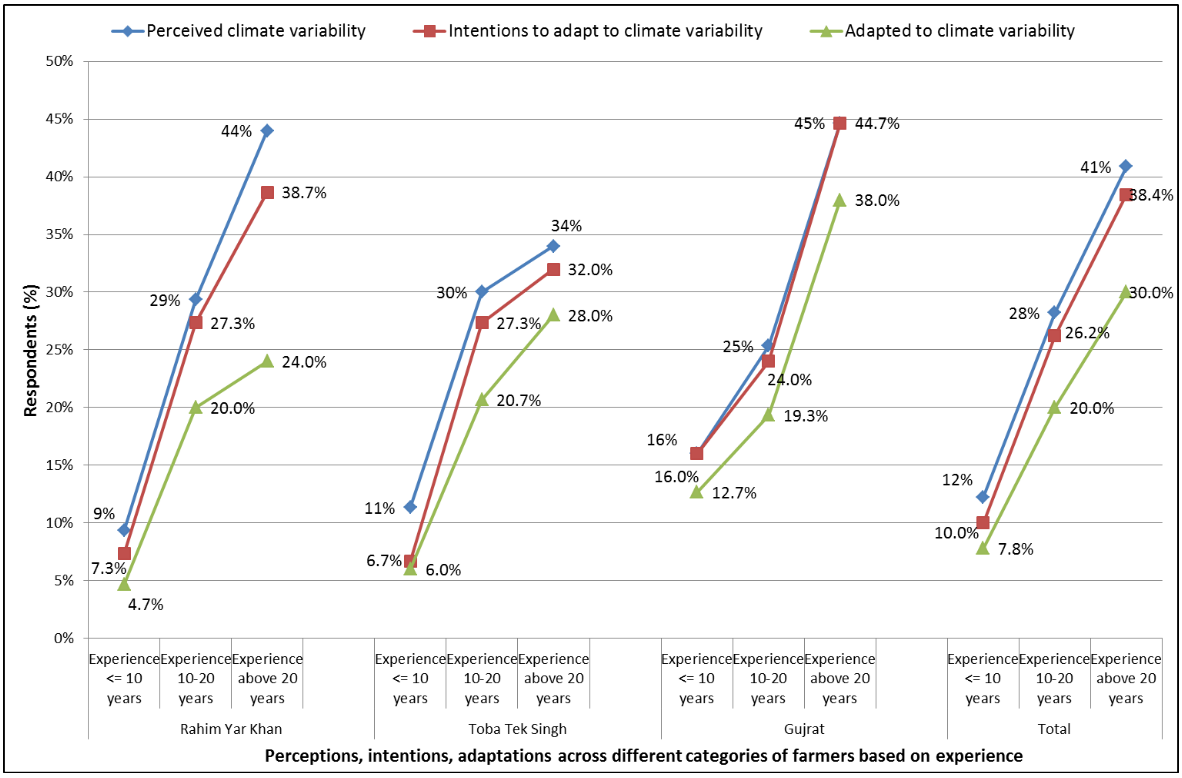
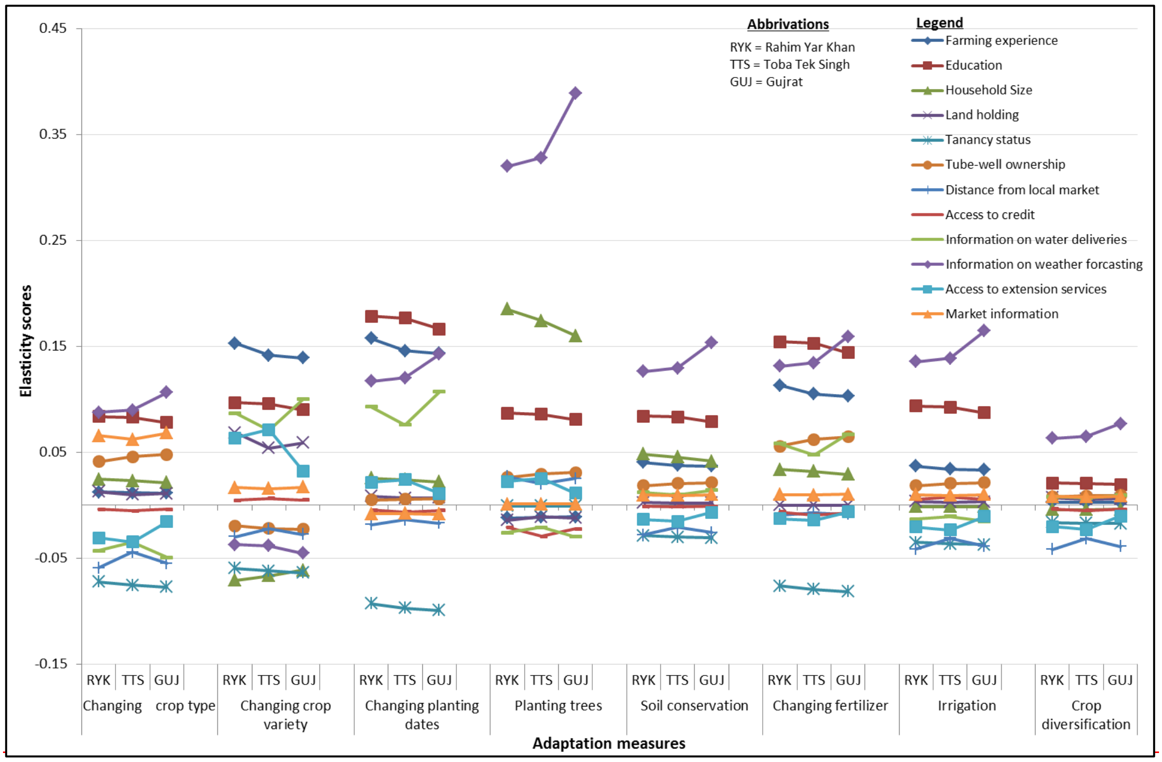


Figure 8~~8~~. Perceptions, intentions and adaptation to climate change across different categories of farmers on farming experience in Punjab


Abbrivations
RYK = Rahim Yar Khan
TTS = Toba Tek Singh
GUJ = Gujrat
Legend
Farming experience
Education
Household Size
Land holding
Tanancy status
Tube-well ownership
Distance from local market
Access to credit
Information on water deliveries
Information on weather forcasting
Access to extension services
Market information
Elasticity scores
0.45
0.35
0.25
0.15
0.05
-0.05
-0.15
RYK
TTS
GUJ
Changing crop type
Changing crop variety
Changing planting dates
Planting trees
Soil conservation
Changing fertilizer
Irrigation
Crop diversification
Adaptation measures

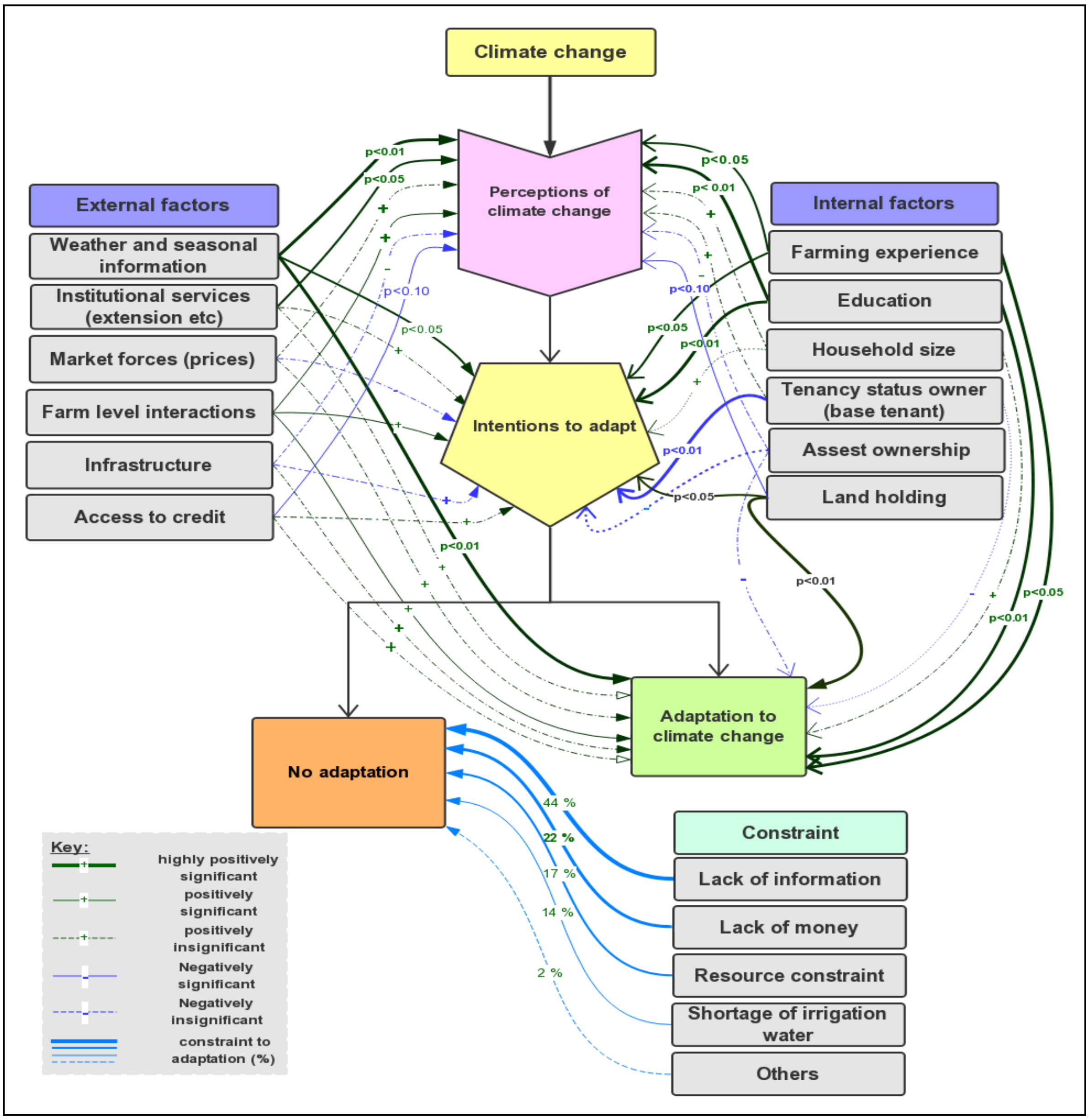


Figure 9~~9~~. Schematic framework of farmers' adaptation process in Pakistan (own illustration)

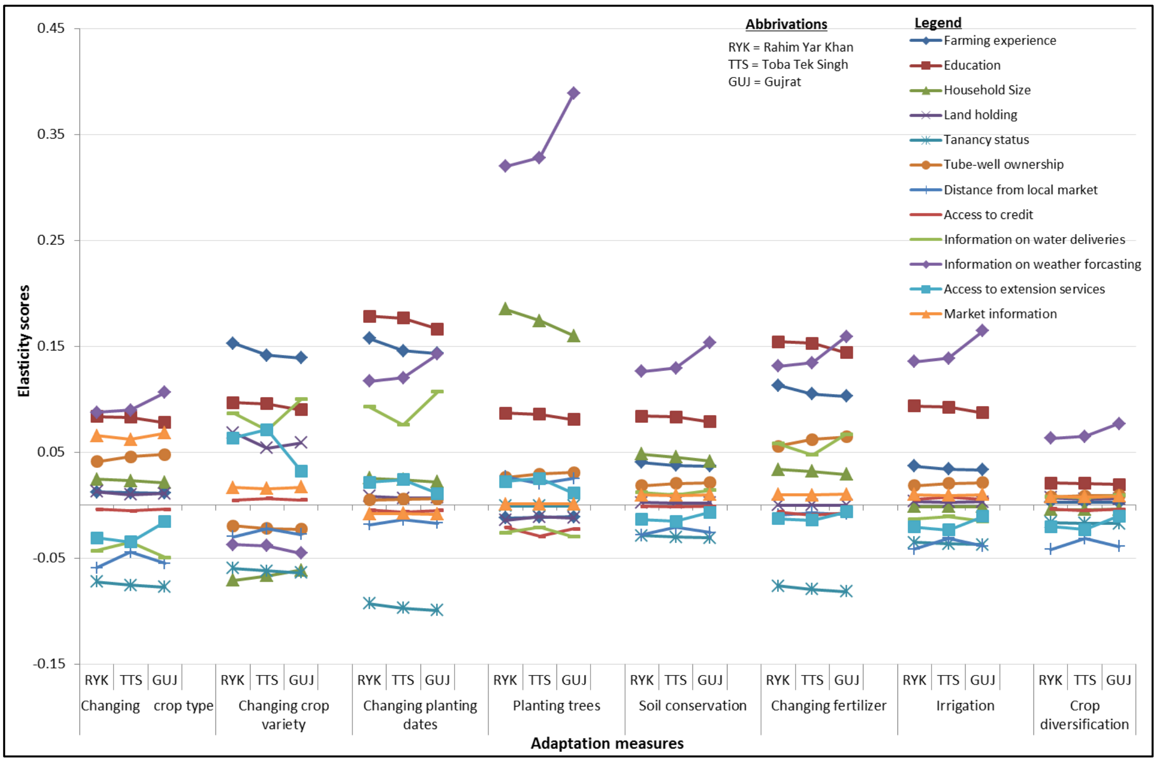


Figure 10. Partial-elasticity calculations across three study districts of Punjab province