Technical Research Studies on

"Impacts of Climate Change on Agriculture and Food Security"

i. **Identification of shifts in cropping patterns under 2 °C scenario**
ii. **Obstacles to the adoption of climate friendly technologies in the farmer fields and possible solutions**

In Collaboration with

US Pakistan Centre for Advanced Studies in Agriculture & Food Security (USPCAS-AFS), University of Agriculture, Faisalabad

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Technical Studies on Impacts of Climate Change on Agriculture and Food Security

a. Obstacles to the adoption of climate friendly technologies in the farmer fields and possible solutions
b. Identification of shifts in cropping patterns under 2^{o}C scenario

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a. Obstacles to the adoption of climate friendly technologies in the farmer fields and possible solutions

Introduction

Technological adoption in agriculture in general and adoption of climate friendly technologies (CFTs) has gained prominence due to mammoth challenge of climate change faced by agriculture sector in Pakistan. Agriculture is both major contributor to GHGs and at the same time biggest victim of climate change related shocks. Adoption of agricultural technologies has been viewed differently due to risky nature of the sector activities and large number and proportion of small holders with limited absorption capacity (economies of scale, financial capital and awareness and literacy to use technologies etc.). CFTs have an added challenge of uncertainty involved in the occurrence of event for which the technologies have been invented. This element discourages the innovators to work in advance for an unforeseeable phenomenon and the adopters due to low expected returns. It is therefore important to understand farm and farmer specific issues in adoption of CFTs.

Climate change has significant impact on agriculture (Lobell et al., 2011) and has potential to further impact it through changing rainfall pattern, drought, floods, increase in average high temperature, etc. The negative effects of these changes are expected to be more common than positive effects. The intensity of negative effects will be higher in developing countries due to high vulnerability and poor economic and technical capacity to respond the menace (Padgham, 2009).

It is threatening small farmers' ability to remain in business in shifting conditions with poor resource base to adapt. This also have implications to increase poor and rich divide.

The literature on climate change adaptation has been focused on quantification of impacts (Hansen et al., 2006; Stern, 2006) and assessment of the vulnerability of communities and ecosystems (Turner et al., 2003; Adger et al., 2007), division of adaptation efforts into structural, physical, institutional categories (Bastakoti et al., 2014), and identification of obstacles to adaptation (Burch, 2010). It is equally important to understand local adaptation measures and constraints and understand nature of adaptation efforts at private and government level. The provision of adaptation goods is categorized into public or private (Tompkins and Eakin, 2012). The nature of adaptation goods provided by private and public institutions can be of public or private and that gives rise to free riding and under-provision. The public goods for adaptation like erosion control upstream to control land erosion downstream discourage private investment as it does not fetch all benefits to environment and the downstream farmers or society at large. Similarly the non-targeted subsidies with benefits to small segment of well-off individuals may results in wastage of resources and trigger inequality.

The government's ability to support the farmers is limited due to resource constraints and extent of the issues in developing countries. The governments in developing countries have urban bias in public investment to support ever increasing urban population and industrial activities. The problem is further aggravated as major part of agricultural investment is allocated for irrigated agriculture due to high expected returns. This has left the rain-fed and other marginal farming with productivity deprived of public support (Zia et al., 1997). The water management, moisture conservation and nutritional management are major agricultural constraints of rain-fed farming and that puts higher reliance on natural forces. It is therefore pertinent to note that variation in rainfall pattern and heat stress due to climate change can heavily hit these areas. In contrast, irrigated agriculture has natural advantage to cope climatic variability.

Different technologies are used in adapting to climate change. Some of those technologies include soil and water conservation (manure application, deep plowing, soil bund-making, etc.), changing sowing dates, crop diversification, crop rotation, water harvesting, income diversification and land renting out and these adaptation strategies are almost similar to those reported in other countries (Rurinda et al., 2014, Mugi-Ngena et al., 2016). Khatri-Chhetri et al, 2017 categorized CFTs in agriculture into Water Smart Technologies, Energy Smart Technologies, Nutrient Smart

Technologies, Carbon Smart Technologies, Weather Smart Technologies, Knowledge Smart Technologies, Food Value Chain Technologies. Water Smart Technologies (WSTs) includes, High

Efficiency Irrigation Systems, Rainwater harvesting, Laser land levelling, Furrow seed-bed and Field Drainage etc. Energy Smart Technologies (ESTs). ESTs are aimed at reducing energy use in agriculture and include Zero Tillage / Minimum tillage, Laser land levelling, Energy efficient field machinery, Solar powered pumps, Direct Seeding of Rice, Precision Agriculture / inputs. Nutrient Smart Technologies include Green manuring and intercrop with legumes and Soil and water testing and recommendation base fertilizers applications etc. Carbon Smart Technologies includes Integrated Pest Management, Agro-forestry, Stall feeding/concentrated feeding to livestock, Local poultry breeds with less feather load. Weather Smart Technologies include, Weather based advisory, Crop insurance based on weather index and Livestock housing etc. Knowledge Smart Technologies include, Agroecological zones based crop planning, Crops diversification, Climate compatible crops calendars, Food Value Chain Technologies. If food waste and losses are considered as a category in countries with GHGs, then it has 3rd largest share after USA and China (FAO, 2011). Keeping in view, quantum of food losses and waste, any improvement will help improving consumable quantity and lower GHGs emission per unit of production. Some of the technologies in this category include, Mechanical Harvesting, Food processing and Cold chain and Dry chain etc.

In Pakistani Punjab, small landholders dominate in the agrarian economy. A large number of factors influence adaptation strategies to climate variability. These include socioeconomic characteristics of farms and farmers. Further, these characteristics also vary across farms and farm households. It is therefore utmost important in understanding of how small landholders perceive climate variability and its impact on their agricultural production and ongoing adaptation measures taken by the farmers. However, we find little evidence indicating the factors influencing adoption of technologies/practices as adaptation measures to climate variability in the rain-fed agriculture of Pakistan.

In a highly diversified country like Pakistan, it is not possible to generalize results for climate change adaptation under a single investigation. Therefore, we used existing primary data for rainfed Punjab (Chakwal district) and irrigated agriculture of Pakistan by using data for Larkana district (Sind) and Jhang district (Punjab). The study has attempted to cover geographical as well as agricultural variation by using different data sets and to cover different aspects of theoretical debates about adaptation and adoption of CFTs.

The present study is designed to address this information gap by investigating adaptations measures taken by the farmers in Pakistan along with determining the influence of socioeconomic characteristics of the farmers on adaptation measures. In the reminder of the paper, the report will separately discuss adoption of CFTs in rain-fed and irrigated agriculture using different theoretical underpinnings.

i. Barriers in adoption of CFTs vis-à-vis public and private good nature– case of Rainfed Punjab

Globally 80% of the agricultural land area is rain-fed which generates 65 to 70% staple foods but

70% of the population inhabiting in these areas is poor due to low and variable productivity. About 69% of all cereal area is rain-fed, including 40% of rice, 66% of wheat, 82% of maize and 86% of other coarse grains (Rosegrant et al., 2002). In Pakistan, the rain-fed areas contribute about 80% of livestock with modest share of 12% wheat, 27% maize, 69% sorghum, 21% millet, 25 % rape and mustard, 77 % gram, 90% groundnut, 53% barley and 85% pulses to agriculture sector (Zia et al., 1996).

Keeping in view the significance of adaptation to rain-fed farming in arid environments, the section is formalized to explore adaptation strategies by household and delineate the factors and barriers for adaptation of public and private nature goods by households and give policy recommendations to promote public goods adaptation in resource constraint rain-fed environment with high vulnerability to climate change. **Study Area and data collection**

The Punjab province being the largest province in term of population is also the major contributor in agricultural production in Pakistan. Further, Punjab province is divided into rain-fed and irrigated Punjab on the basis of mode of irrigation. The northern part of Punjab province (aka Pothwar plateau) is comprised of rain-fed farming system. The climate of this region is predominantly semi-arid. The rainfall follows erratic pattern with most of the rainfall (about 70% in months of June-September i.e. summer season while the winter season gets long spells of gentle showers. The area has generally slightly undulating slopes with low hill ranges. Arid region of the province is exposed to adverse effects of climate change. Chakwal district was selected from the as agriculture production in the district predominantly depends on rainfall. This district is also the most important area for wheat production among rain-fed farming area of the Punjab. Two cropping seasons namely *rabi* (October-April) and *kharif* (May-September) seasons are traditionally followed keeping in consideration the rainfall probabilities and temperature for different crop growth stages. Wheat and peanuts are the important crops planted in the study area. A total of 190 farmers were interviewed. A well-structured, pre-tested questionnaire was used to gather information. The questionnaire included a number of closed-ended and open-ended questions on socioeconomic characteristics, adaptation to climate change, farm assets, etc. In addition, the respondents were asked to provide qualitative information on farmers' decision to carry activities or to invest in adaptation to climate change in the response to the perceived actual or potential changes. This sort of information was sought to understand reasons for carrying out activities or investing in adaptation to climate change. We considered activity or investment as an adaptation strategy if it was taken as a conscious investment to solve climate change related problem. We considered six adaptation strategies to climate change including manure application, deep plowing, bund-making, income diversification, crop diversification and land renting-out. Services of four postgraduate students from rural background with primary degree in agricultural economics discipline were hired to collect data during 2013. This helped to get information in native language and translate local language and terminologies.

Empirical methods

Based on the benefits and costs of adaptation to climate change, we followed classification of adaptations into two broad categories (following Tompkins and Eakin, 2012) of 'private adaptation' resulting in private benefits only and the 'private adaptation' resulting in huge public benefits. Private adaptations for private benefits are those adaptations where the actions are taken by individuals and all the benefits are accrued to the individuals (Tompkins and Eakin, 2012). Deep plowing and manure application are examples of adaptations with private benefits. On the other hand diversification of income and crops, bund-making, and renting-out land area are other private adaptations to climate change and the owners bear the costs of adaptation whereas such adaptation decisions create public goods. So these adaptations are called private adaptation for public benefits. Diversification of income and crops is linked with the increased economic activities in the rural areas. Similarly, decision on renting-out land creates public good as this decision provides benefits to tenants and landless farmers. Bund-making is used to avoid soil erosion. However, its benefits are availed by the neighboring farmers as well through declining soil erosion.

A number of farm, farmer and socio-economic characteristics affect the decision on adaptation to climate change. Gender, age, education and experience are important among the farmer characteristics (Knowler and Bradshaw, 2007; Vitale et al., 2011; Baumgart-Getzet al., 2012).

D'Emden et al. (2008) and Gedikoglu and McCann (2012) find that farm size, location, proximity to house, access to irrigation and the agro-ecological and socio-economic conditions of the area are important determinant of adoption decisions. The economic theory explains that farmers decide to make investment in adaptation to climate change when the expected utility of adaptation (D_1*) is greater than the utility of non-adaptation (D_0*). Thus decision on adaptation is observable as a dichotomous choice i.e. $D_i = 1$ if $D_i^* > D^*_0$, otherwise $D_i = 0$. This can be modeled as:

$D_i^* = Z_i\beta + \varepsilon_i$ with $D_i = 1$ if $D_i^* > D^*{}_0$, otherwise $D_i = 0$ (1) where Z is a matrix of the explanatory variables, β is a vectors of parameters to be estimated and ε_i is the error term.

Logit model is used to estimate equation 1 as the dependent variable is the dummy of adaptation to climate change i.e. farmers that adapt to climate change and those that don't adapt to climate change. As mentioned earlier, the adaptation to climate change considered in the present study is of two types such as private adaptation for private benefits and private adaptation for public benefits. The former further includes two types of adaptation (deep ploughing and manure application) and the latter comprises four adaptation practices (bund making, income diversification, crop diversification, and renting-out land) reported by the respondents in this study. Thus six separate logit models are estimated using maximum likelihood as these models cannot be consistently estimated using ordinary least square because of the dummy dependent variable in all the six logit models. The logit model is defined as follows:

$$P(D = 1) = \frac{\exp(Z_i\beta)}{1+exp(Z_i\beta)} \qquad (2)$$

$$P(D = 0) = \frac{1}{1+exp(Z_i\beta)} \qquad (3)$$

Where D takes the value 1 if the farmer adapts to climate change and 0 otherwise. Z is the row vector of independent variables and β the corresponding parameter vector to be estimated. Details of dependent variables and explanatory variables used in the above models is presented in Table

1.

Results

Socioeconomic characteristics

We employed six different logit models. Dependent variables considered in the study are manure application, deep plowing, crop diversification, income diversification, bund-making and renting out land. Considering first two adaptation to climate change, 62 and 38% respondents are found adaptors whereas 54% respondents are found using bund-making as adaptation to climate change. The respondents reporting income diversification are 73% and only 30% farmers are found diversifying crops. The most common adaptation to climate change is land renting out (82%) to fellow farmers (Table 1).

Explanatory variables in the model include age, education, farming experience, family size, male and female above 15 years age, farm size, livestock, ownership of tractor and rotavator and distance of the farm from the city. Descriptive statistics given in Table 1 show that the respondents are around 51 years old with average education of approximately 8 schooling years. The respondents reported farming experience of 21 years, indicating that the respondents have substantial experience in farming and they have learnt the better farm practices through experience and observations. Pakistan is among the densely population countries in the world and the present study depicts that the respondents have large family size i.e. 8 family members and mostly family size comprises children as evident from small number of males and females above 15 years of age. Small farms dominate in the study area as indicated by 7.75 acres land area owned by the respondents. Further, small landholding induces farmers to diversify income so the study finds average 3 livestock units. Ownership of farm machinery is considered an important asset in adaptation to climate change. We find that 33% farmers possess tractor whereas rotavator is found among 4% farmers only.

Distance of the farm from the city is important for having access to information and markets and the mean distance is found to be approximately 10 km that is quiet long distance.

Table 1: Socioeconomic characteristics and adaptation

Characteristics	Unit	Mean	Standard deviation
Socioeconomic characteristics			
Age	Years	50.55	11.99
Education	Schooling years	7.72	3.65
Farming experience	Years	21.36	12.93
Family size	Numbers	8.21	2.84
Males above 15 years	Numbers	2.28	1.14
Females above 15 years	Numbers	1.87	0.95
Land area	Acres	7.75	15.29
Livestock	Animal units	3.02	3.43
Tractor	Yes=1	0.33	0.47
Rotavator	Yes=1	0.04	0.18
Distance from city	Km	9.98	7.75
Private adaptation for private benefits			
Deep plowing	Yes=1	0.38	0.48
Manure application	Yes=1	0.62	0.49
Private adaptation for public benefits			

Bund making	Yes=1	0.54	0.50
Income diversification	Yes=1	0.73	0.44
Crop diversification	Yes=1	0.30	0.46
Land rented out	Yes=1	0.82	0.38

Model results of private adaptation for private benefits

The empirical results obtained from logit models of private adaptation for private benefits are given in Table 2. It is evident from the results of both models that most of the exogenous variables are significantly related with adaptation to climate change i.e. manure application and deep plowing. Livestock is important in explaining the adoption of manure application as the larger the livestock units will result in the higher probability of applying manure at the farm. The farmers having tractor are more likely to apply manure at their farms, since tractor is mostly used for transportation of manure. Two variables namely farming experience and the distance from the city/market have significant negative relationship with the adoption of manure application.

Since crop production on the farms located in the rain-fed region depends on precipitation, conservation of moisture through deep plowing is the utmost important farming practice and it has become critical in the presence of climate change. Education of the respondents is significant at 1% level of significance and it has positive impact on adaptation of deep plowing, implying that increase in schooling years by 1%, increases probability of adapting deep plowing by 0.25%. Family size and number of males above 15 years age are positively related to adapting deep plowing and these variables statistically different from zero at 1% level of significance. This indicates that households with large adult family members are more likely to adapt to climate change. A positive and significant coefficient of tractor ownership ($p < 0.01$) implies that the respondents having tractors are highly likely in adapting deep plowing. The result was expected because tractor ownership makes it convenient for farmers to go for deep plowing.

Table 2: Private adaptation for private benefits and determinants

VARIABLES	Manure applied	Deep plowing
Age	0.04*	-0.03
	(0.02)	(0.02)
Education	-0.01	0.25***
	(0.05)	(0.06)
Farming experience	-0.08***	0.04*
	(0.02)	(0.02)
Family size	0.04	0.26***
	(0.08)	(0.07)
Males above 15 years	-0.03	-0.49***
	(0.18)	(0.19)
Female above 15 years	-0.22	-0.35
	(0.23)	(0.22)
Owned land area	-0.02	0.00
	(0.02)	(0.01)
Livestock units	0.23***	-0.03
	(0.07)	(0.05)
Tractor ownership	2.03***	0.94**
	(0.45)	(0.37)

Rotavator ownership	0.85	
	(1.17)	
Distance from city	-0.05**	-0.04
	(0.02)	(0.02)
Constant	-0.12	-2.10*
	(1.15)	(1.19)
LR Chi^2	62.67***	47.81***
Observations	198	191

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Model results of private adaptation for public benefits

The results of the logit models for private adaptation for public benefits are given in Table 3. The coefficients on education, farming experience, family size and farm owned area are positive and statistically different from zero for bund-making adaptation. These results indicate a strong association between exposure to technology and adaptation. In case of income diversification, significant variables are age of the respondents, farming experience and livestock units. Education, family size, number of adults, tractor and distance from the city are significantly associated with crop diversification. Land renting-out is another private adaptation for public benefits as this adaptation results not only in benefits to the owners of the farm but it also provides benefits to others having no and or a few acres of land. Owned land area, tractor and number of male above 15 years are significantly related with this adaptation to climate change. Variables namely tractor ownership and owned land area are negatively associated with land renting-out whereas numbers of males in the family has positive effect on land renting-out.

Table 3: Private adaptation for public benefits and determinants

VARIABLES	Bund-making	Income diversification	Crop diversification	Land renting out
Age	0.02	0.06**	0.04	-0.02
	(0.02)	(0.03)	(0.03)	(0.03)
Education	0.29***	0.13	0.15*	-0.08
	(0.06)	(0.08)	(0.08)	(0.08)
Farming experience	0.05**	-0.05*	0.02	0.00
	(0.02)	(0.03)	(0.03)	(0.03)
Family size	0.39***	-0.04	0.16*	-0.07
	(0.09)	(0.11)	(0.09)	(0.09)
Males above 15 years	0.33	0.27	0.73**	0.54*
	(0.20)	(0.25)	(0.28)	(0.31)
Female above 15 years	-0.13	0.28	0.56*	0.52
	(0.24)	(0.32)	(0.31)	(0.35)
Owned land area	0.09**	-0.00	0.00	-0.34***
	(0.04)	(0.06)	(0.02)	(0.07)
Livestock units	0.04	1.82***	-0.04	0.13
	(0.06)	(0.30)	(0.08)	(0.08)

Tractor ownership	0.68	-1.01	4.98***	-1.18**
	(0.42)	(0.65)	(0.70)	(0.58)
Rotavator ownership	-1.27	-0.90	-1.67	0.17
	(1.07)	(1.18)	(1.56)	(1.46)
Distance from city	-0.01	0.00	0.06*	0.01
	(0.02)	(0.04)	(0.03)	(0.03)
Constant	-8.68***	-4.79***	-8.74***	4.59***
	(1.59)	(1.68)	(2.14)	(1.71)
LR chi2	84.65***	123.69***	136.34***	82.93***
Observations	198	198	198	198

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Discussion

Technology adoption for adaptation is taken by farmers to reduce the risk of climate change (Di Falco et al., 2011). Soil bunds, tree planting, water harvesting, contour plowing and cultivation of hedges are the most common adaptation strategies in the dry and rain-fed regions (Di Falco and Bulte, 2013). Income diversification is another risk mitigating adaptation strategy in the developing world (Eliss, 2000; Chavas and Di Falco, 2012, Wuepper et al., 2017). In the present study, we find that the most common adaptation strategy is land renting-out being the private adaptation for public benefits. Applying manure to conserve soil fertility is the most common private adaptation for private benefits. The least adapted strategy is crop diversification among all adaptation strategies. Many of the reported adaptation strategies in the present study are similar to those of Di Falco and Bulte (2013). Income diversification is the tool used by 73% farmers to reduce the risks posed by climate change. Farmers living in the rural areas of Pakistan have no or little access to credit and capital. These factors induce farmers to diversify in order to make more income security. (Reardon, et al, 2006; Ellis, 2004; Lanjouw & Lanjouw, 2001). Deininger & Olinto (2001) find that farm households choose to diversify into non-farm economic activities to reduce risk. Farmers of the study area are characterized with small landholding, lack of access to credit and capital. These characteristics may enforce rural households and their members to diversify farm activities.

Human capital such as education, farming experience and family size is important determinant of deep plowing for moisture conservation, soil bund-making and income diversification. With high schooling years, the farmers have access to information relating to the best adaptation strategies. Significant coefficient of education variable implies an important role in adaptation to climate change. Statistics also show a relatively higher literacy rate of Chakwal district compared to average of the Punjab province. This is in line with Pali et al. (2002) and Mugi-Ngena et al. (2016) who found a positive influence of education on the soil water conservations and soil fertility management. Skoufias, Bandyopadhyay and Olivieri (2015) argue that education is strongly related with diversification in agriculture-related activities in India.

Farming experience learnt over the years enables farmers in making decisions in the right direction to reduce the ever increasing risk to their farms. Soil bund-making adaptation strategy is one such practice taken by the farmers to conserve their farms. This corroborates Mugi-Ngena et al. (2016) who observed that farming experience was significant in explaining farmers' adaptation to climate variability in regard to water harvesting strategy. Maddison (2006) argues that less experienced farmers have less knowledge and information to climate change and adaptation strategies to be taken in order to reduce the effects of climate change. Although soil bund-making, being an adaptation strategy is private in nature, it results in public benefits as the neighboring farmers with relatively low lying farms also avail advantages. The reason lies in the fact that flow of water and soil erosion intensity will decline due to soil bund-making done by the former farmers. On the other hand, negative association of farming experience with income diversification is due to the reason that experienced farmers stick to their age-old reliance on agriculture production and they are reluctant to take risk in diversifying sources of income. Farming experience is also related with manure application. Farmers mostly obtain manure from livestock farming which is labor intensive and highly risky farming activity. Since experienced farmers have mostly risk averse behavior and therefore rarely invest in livestock farming. With no or little livestock units, such farmers may have no manure and thus may not be able to apply manure at their farms. However, farming experience is positively associated with deep plowing adaptation strategy. Moisture or water conservation through deep plowing is totally private adaptation with private benefits and the experienced farmers are in a better position to invest in this type of adaptation strategy because of their knowledge and expertise of previous years in conserving rainwater through deep plowing.

These results are supported by Maddison (2006) and Mugi-Ngena et al. (2016) who found the important role of farming experience in adaptation to climate variablity.

Farm mechanization is very low in Pakistan and it is particularly evident in the rain-fed areas of Punjab province where farmers have very small landholdings and their farm production depends on precipitation. Even tractors and basic implements are not sufficient to perform traditional farm practices. Statistics show that there are only 6315 tractors for 166 thousands rural households in Chakwal district (Government of Punjab, 2016), depicting that mostly farmers depend on their fellow farmers for the tractor and other machinery services. Tractor ownership has strong role in adaptation to climate change as its ownership is positively related with deep plowing, manure application and crop diversification. All these strategies involve high use of farm machinery and farmers having tractor and other machinery. However, this variable is negatively related with land renting-out adaptation strategy. It is not economical for farmers having tractor and other farm machinery to renting out their farm area, otherwise operating tractor and other machinery at the remaining farmer will not be economical farming practice. Owned land area variable has negative coefficient on renting-out adaptation. Negative relationship indicates that such farmers face greater difficulty in renting-out farm area as their staple food heavily depends on farm production and they may not take risk of relying on staple food obtained from the fellow farmers, since the first priority for the small landholders is the staple food i.e. wheat. Owned land area and soil bund-making are positively associated and this relation implies that farmers prefer to make investment in adaptation to climate change at their own land. Increasing owned land area by 1% will increase the probability of soil bund-making by 0.09%. This result is also in line with Anley et al. (2007) and Mugi-Ngena et al. (2016) that farmers with large farm size were found in investing water and soil conservation technologies.

Number of household members were significant in explaining the influence on deep plowing, soil bund-making and crop diversification. This implies that the farm households with large number of household members are more likely to have adaptation strategies in regard to the use of deep plowing, soil bund-making and crop diversification. These adaptation strategies are labor intensive practices and households with large family size can manage labor force requirement though their family members. This corroborates Dolisca et al. (2006), Anley et al. (2007), Nyangena (2007) and Mugi-Ngena et al. (2016) in that large family size enables farmers to take decision in favor of labor intensive adaptation strategies to climate variability.

Recent years have seen significant success on policy frontier and now besides Climate Change

Policy (2012) and climate change act-2017, there is a national food security policy, National Water

Policy, and provincial Agricultural policies for Punjab, Sindh, and KPK provinces all approved in 2018. As after the 18th amendment agriculture became provincial subject, a functional linkage of provincial agricultural systems to federal food security, climate change and water/irrigation components. Although national climate change policy document attempted to explain impacts of climate change on water resources and Agriculture and has provided possible solutions through research, technology development, capacity building, risk assessment etc, the provincial agricultural policies did not give heed to the issue to the needed extent. Among provincial policies, the agricultural policy of Punjab has highlighted needs for zoning and zone-specific smart agriculture practices and need for safety nets, insurance and finances. The Sindh and the KPK policy documents highlighted significance of climate change but lack any plan to combat the climate change menace. A closer look at the federal level policy documents and the provincial agricultural policy documents clearly shows this disconnect. Another disconnects comes from lack of operational mechanisms, budgetary allocation and administrative roadmap to implement nonchalantly drafted adaptation and mitigation policy objectives in federal and provincial policy documents. The focus should be provision of public good nature CFTs either directly by public R&D or support to the private R&D in its provision and protection of intellectual property. The capacity of government and non-government departments must be upgraded to hunt Green Climate Fund.

ii. Barriers to adoption Vis-à-vis farmers' specific endowments and perception – case of irrigated Sind and Punjab

Pakistan is predominantly under irrigated agriculture. As compared to rainfed agriculture, where rainfall is major constraint, land area also gets equal prominence in farming and adaptation decisions in the irrigated agriculture. This section attempts to understand adoption of CFTs and adaptation measures from farmers' perspective by looking at variation in their endowment of their natural and physical infrastructure as well as perception about factors contributing to climate change. The section discusses provincial variation and adapters Vs non-adapters responses separately in the reminder of the section.

Punjab and Sindh are major contributors in national economy particularly these are important provinces in provision of food security, employment generation and exports of textile and related goods. However, in the recent past, like other developing countries, farmers from these provinces are facing different challenges in coping climate change. Data collected from 212 respondents in Larkana (Sind province) and 165 respondents from Jhang (Punjab province) by WWF is being used in the study. Table 4 provides social and economic profiles of the farmers in Punjab and Sindh provinces of Pakistan. We find that farmers in Sindh have relatively small family size compared to those of Punjab province. However, famers are more literate in Punjab province. This may be due to the large farm size owned by the farmers in Punjab. Distance from home to farm fields is higher in Punjab, mainly because of settled village culture in Punjab. Contrary to distance from farmer fields, we find that farms in Sindh are located at higher distance from input market (9.31 km) than Punjab (7.91). Villages in

Punjab are more populated than Sindh province. Same is the case with relatives of farmers living in the village. This speaks of strong family networks existing in Punjab and Sindh provinces.

Table 4. Socioeconomic profile of the respondents

Characteristics	**Sindh**		**Punjab**	
	Mean	**SD**	**Mean**	**SD**
Age (years)	46.10	14.41	46.19	14.49
Family size (#)	4.38	2.55	9.77	4.00
Education (schooling years)	1.15	0.61	5.38	2.848
Farm size (acres)	2.98	8.53	7.95	10.214
Home to farm distance (km)	2.38	0.68	6.26	26.09
Distance from input market (km)	9.31	6.29	7.91	6.48
Village population (#)	1727.18	1730.27	1990.65	2866.62
Relatives (#)	121.90	313.05	242.34	315.25

What do farmers of an increase in output, prices of inputs and output are reported in Figure 1. From Figure 1, we can see that farmers from Sindh province perceive larger increases in overall agricultural output, input prices and output prices. Although farmers from Punjab also observe an increase in output and prices, the increases reported from farmers in Punjab province are far lower. One reason may be time and intensity of introduction and adoption of new technologies in both provinces. It is considered that new technology in agriculture was adopted slowly and very late in

Sindh province compared to Punjab province. Farmers from Punjab province realized benefits of rising production many years ago. So asking the increase in output and prices during the last year is reported a small increase in Punjab province.

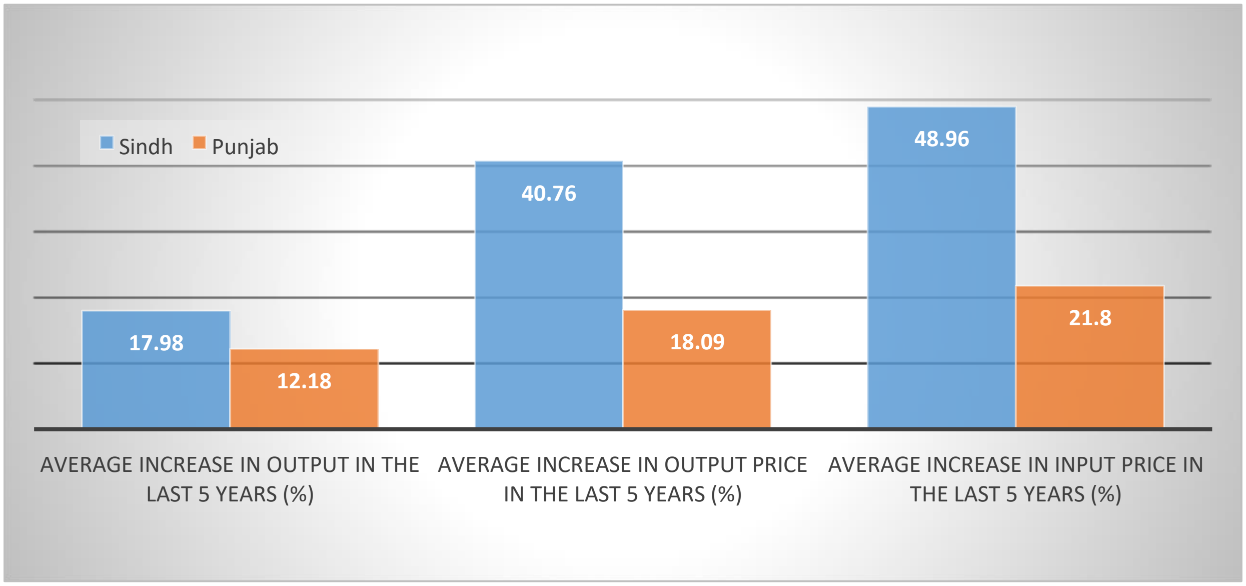

Figure 1. Perception of the farmers regarding changes in input and output prices (%)

Adaptation practices reported by the farmers

Climate change is threatening agriculture and farmers are at higher risk of its adverse effects due to weak resilience and coping strategies available to them. We asked farmers about the possible practices they are adapting to climate change on their farms. Table 5 provides information on important adaptation practices reported by the respondents. Delayed sowing, early and late harvesting, including livestock and or fishing in farming activities, off-farm job and sharecropping are the important adaptation practices. Among all these practices, the most commonly adapted practice is delayed sowing in Sindh (8%) whereas livestock/fishing is the commonly practiced in Punjab (80%). Delayed sowing is reported by 16% in Punjab province. Further, adaptation of various practices is very small in Sindh province compared to Punjab province. There may be different hurdles in adaptation to climate change in Sindh province. Lack or access to information, low literacy and less extension services can be possible reasons for low adaptation score in the province.

Table 5. Adaptation practices reported by the respondents

Adaptation	**Sindh**		**Punjab**	
	Mean	**SD**	**Mean**	**SD**
Delay sowing	0.08	0.37	0.16	0.37
Early harvesting	0.01	0.09	0.11	0.86
Late harvesting	0.01	0.07	0.02	0.31
Livestock, fishing	0.005	0.07	0.80	0.73
Off-farm job	0.001	0.09	-	
Share-cropping	0.005	0.07	0.08	0.41

Table 6 provides insights on difference of socioeconomic characteristics of adaptors and nonadaptors in the study area. Family size among adaptors is comparatively large than non-adaptors. Since adaptation to climate change involves labor intensive farm practices such as livestock and or fishing, the demand for labor thus rises. Households with large family size can easily manage labor demand for new adapted practices at their farms. Access to knowledge and information is considered critical factor in adaptation to climate change. This is also true in the present study as we find higher schooling years among adaptors (4.42 schooling years) than non-adaptors (1.96 schooling years). Large farm size also induces farmers to adapt to climate change because they can afford investment on practice compared to those with small farm size. In the present study, adaptors possess large farm size compared to non-adaptors. Easy access to input and output market is assumed to facilitate adaptation process among the farmers. This is also the case with the present study. Adaptors are relatively located at smaller distance from input market than non-adaptors. The access to market makes it possible farmers to acquire new information about possible adaptation practices at their farms. Availability of public transport is another deciding factor in adaptation to climate change. Since developed markets are located away from villages and farmers having public transport find it possible to visit the market with ease. Visiting market and purchasing climate smart farm inputs are facilitated by public transport. We find that 61% adaptors have access to public transport than non-adaptors (36%). This implies the importance and critical role of public infrastructure development in the rural areas in order to prepare farmers in adapting to climate change.

Table 6 Comparison of socioeconomic characteristics of adaptors and non-adaptors

Characteristics	**Adaptors**		**Non-adaptors**	
	Mean	**SD**	**Mean**	**SD**
Family size	9.14	4.29	6.68	4.05
Age	46.13	13.79	46.19	15.55
Education	4.42	3.11	1.96	2.08
Farm size	7.22	11.54	3.24	4.74
Distance from home to farm	5.41	24.22	3.08	5.74
Market distance	7.87	6.55	9.66	6.06
School in village	0.88	0.32	0.93	0.25
Dispensary	0.44	0.49	0.31	0.46

Shopping market	0.68	0.47	0.76	0.43
Public transport	0.61	0.48	0.36	0.48
Electricity	0.88	0.32	0.88	0.32

Observations/experiences of farmers regarding climate change

Farmers decide actions while considering their past experiences and observations on their own farms or neighboring farms. This also applies to adaptation to climate change. Farmers were asked to provide their observations/experiences on different climatic factors over the past 15 years. Table

7 provides this information. Non-adaptors claim that they don't find a change in rainfall during the mentioned time period compared to 3% of adaptors. 15% adaptors are of the view that rainfall has increased over the last 15 years whereas this percentage is only 4% among non-adaptors. Number of more hot days are reported by 18% adaptors and 7% non-adaptors. Adaptors (41%) are of the view that flash floods have increased over the last 15 years compared to 38% non-adaptors. The percentage in favor of climate change is very low among non-adaptors with a few exceptions compared to adaptors to climate change. This necessitates to improve knowledge and build capacity of farmers in adaptation to climate change so farmers may be able to cope with rising threats of climate change in the coming years.

Table 7. Perceptions of farmers regarding climate change

Characteristics	**Adaptors**		**Non-adaptors**	
	Mean	**SD**	**Mean**	**SD**
No change in rainfall	0.03	0.17	0.56	1.30

More rainfall in the last 15 years	0.15	0.36	0.04	0.18
No change in temperature	0.01	0.12	0.24	0.44
Number of more hot days	0.18	0.39	0.07	0.25
Number of less hot days	0.05	0.22	0.23	0.42
Increased cold spells	0.01	0.06	0.12	0.32
Flash floods increased	0.41	0.49	0.38	0.48
Windstorm increased	0.11	0.32	0.08	0.74
Hailstorm increased	0.02	0.15	0.28	0.69

Conclusions and policy implications

Adaptation to climate change is practiced by the farmers to mitigate the climate related risks. Adaptation through technology adoption can be based on decisions made by individual (private), community and public sector organizations. Private adaptation further can have benefits for individuals and public. The present study was designed to investigate private adaptation to climate change in the rain-fed agriculture in Punjab, Pakistan. The rain-fed agriculture in the north of Punjab is characterized with small landholdings, low farm mechanization, highly dependence on precipitation, semi-hilly topography, and pre-dominant traditional farm practices. Adaptations reported by the respondents were categorized into adaptation for private benefits (applying manure and deep plowing) and adaptation for public benefits (soil bund-making, income diversification, crop diversification and land renting-out). Land renting-out, income diversification and manure application were common adaptation to climate change in the study area. Several socioeconomic factors of farm households were likely to influence adaptation to climate variability. The role of education of the respondents was important in deep plowing, soil bund-making and crop diversification. Farming experience was significantly affecting manure application, deep plowing, soil bund-making and income diversification. Farm households were found capitalizing their family size in deep plowing, soil bund-making and crop diversification. However, adult male members in households had an important role in crop diversification and land renting-out strategies as adaptation to climate change. Farm machinery i.e. tractor ownership was significant determinant of manure application, deep plowing, crop diversification and land renting-out.

Results of the study indicated that a host of socioeconomic factors of rural households in the rainfed agriculture dictated farmers' response to climate variability, studying the role of these factors is inevitable for designing solid policy interventions for adaptation to climate variability. Results of the study implies that the policy-makers, researchers and regional planners can build on this work by undertaking more interdisciplinary research approach to find the most suitable adaptation strategies at individual and community levels. This becomes vital for heterogeneous rural households because some households have better capacity in adapting to climate variability compared to their fellow farmers. This necessitates to tailor adaptation policies while considering different biophysical and socioeconomic circumstances.

Education and farming experience, being the significant factors influencing the use of adaptation strategies imply that awareness about adaptation strategies is important area to be focused in policy interventions for adaptation to climate variability. Education and training programs are already organized for the farmers by the Department of Agriculture, Government of Punjab. Capacity building and training of agricultural extension agents should be encouraged in the routinely basis training programs for the extension agents. Thus extension agents with updated knowledge on adaptation strategies to climate change can encourage farmers through non-formal education programs in lightening and sensitizing farmers in efficiently utilizing the available resources for curbing the effects of climate variability.

Family size and farm machinery, being the important factors of adaptation to climate change indicate the need to introduce labor saving technologies especially through farm mechanization.

Mostly adaptation strategies are labor intensive farm practices such as crop diversification and soil bund-making. Presently, farm machineries available in the market are particularly designed for large landholders. Small landholders are not able to afford and operate optimally considering few hectares of landholdings. Thus, there is a need is to invest in farm machineries suited to small landholders. The policy makers should give due focus to public sector interventions in the form research and development to help these resource scarce rain-fed farming communities and also find ways to support the private adaptations providing public goods for benefit of environment and the society at large. Future research should consider the nature of public sector adaptation efforts and the related distributional issues among community members. Moreover, the village commons are facing additional threats and demand for ever bigger contribution for sustainability. The future research should address climate change related additional costs and resultant benefits and their distribution to members to develop a multidimensional understanding about adaptation to climate change. Specific policy instruments to promote adoption of public good nature CFTs may include provision for compensation for positive externalities directly through climate fund or subsidies or through use of mix of economic and regulatory instruments along with moral suasion to ecourage and compensate the producers.

Specific observation, while looking spatial variations, brings variation in socioeconomic characteristics and natural and physical capital endowments (as is the case in study comparing selected respondents from Sind and Punjab). Moreover, variation in perception about climate related indicators, shape adaptation behavior. This shows significance of knowledge and awareness in shaping adaptation behavior.

Way forward

The data used in this study was limited to technologies and practices currently adopted by farmers. Due to random selection of farmers, the probabilities of practices more common among farmers are reflected in sample. Moreover, limited agroecological and cropping zone coverage restricted the scope of research to technologies adopted in the selected rainfed and irrigated cropping zones. In order to understand technological adoption, a broader coverage in terms of study area and a much larger sample size is recommended. Moreover, to understand hurdles in adoption, a set of technologies can be selected and tested for adoption in terms of farmers' concerns like Trust in technology, Trust in government / technology providers, Perceived usefulness of CFTs, Perceived ease of use of CFTs, Suitability to local conditions. Similarly, in order to understand technological,

Institutional and social (Economic, Cultural, Psychological) barriers, experts' interviews should be added to deeply investigate issues like, Technical performance of CFTs, Potential for adoption/deployment – availability of skilled labor and O&M, Current market potential and adoption trends, Financial and economic attractiveness, excluding GHG mitigation benefits (and other difficult to quantify externalities).

References

Adger, W. N., Agrawala, S., Mirza, M. Q., Condé, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B., Takahashi, K. (2007). Assessment of adaptation practices, options, constraints and Conceptualising Climate Change Governance 21 capacity. In: M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden & C. E. Hansen (Eds.), Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group ii to the fourth assessment report of the intergovernmental panel on climate change (IPCC) (pp. 717–743). Cambridge: Cambridge University Press.

Anley, Y., Bogale, A., Haile-Gabriel, A. (2007). Adoption decision and use intensity of soil and water conservation measures by small holder farmers in Dedo district, Western Ethiopia. Land Degradation and Development, 18:239-302.

Bastakoti, R.C., Gupta, J., Babel, M.S. (2014). Climate risks and adaptation strategies in the Lower Mekong River basin. Regional Environmental Change, 14(1): 207.

Baumgart-Getz, A., Prokopy, L. S. and Floress, K. (2012). Why farmers adopt best management practices in the States, United: A meta-analysis of the adoption literature. Journal of Management Environmental, 96:17–25.

Chavas, J. P. and Di Falco, S. (2012). On the role of risk versus economies of scope in farm diversification with an application to Ethiopian farms. Journal of Agricultural Economics, 63:25–

55.

D’Emden, F. H., Llewellyn, R. S. and Burton, M. P. (2008). Factors influencing adoption of conservation tillage in Australian cropping regions. The Australian Journal of Agricultural and Resource Economics, 52:169–182.

Deininger, K., & Olinto, P. (2001). Rural Nonfarm Employment and Income Diversification in Colombia. World Development, 455–465.

Di Falco, S. and Bulte, E. (2013). The impact of kinship networks on the adoption of riskmitigating strategies in Ethiopia. World Development, 43:100–110.

Di Falco, S., Veronesi, M. and Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. American Journal of Agricultural Economics, 93:829–846.

Dolisca, F., Carter, R., McDaniel, J., Shannon, D., Jolly, C. (2006). Factors influencing farmers’ participation in forestry management programs: a case study from Haiti. Forest Ecology and Management, 236:324-331.

Ellis, F. (2004). Occupational Diversification in Developing Countries and the Implications for Agricultural Policy. London: Programme of Advisory and Support Services to DFID (PASS). Gedikoglu, H. and McCann, L. (2012). Adoption of win-win, environment-oriented and profitoriented practices. Journal of Soil and Water Conservation, 67:218–227.

Government of Punjab. (2016). Punjab Development Statistics. Punjab Bureau of Statistics, Government of Punjab, Lahore.

Hansen, J., M. Sato, R. Ruedy, K. Lo, D.W. Lea, and M. Medina-Elizade. (2006). Global temperature change. Proceedings of National Academy of Science, 103:14288-14293.

Khatri-Chhetri, Arun, P.K. Aggarwal, P.K. Joshi, S. Vyas. 2017. Farmers' prioritization of climatesmart agriculture (CSA) technologies. Agricultural Systems, Volume 151, pp184-191.

Knowler, D. and Bradshaw, B. (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy, 32:25–48.

Lanjouw, J. O. and Lanjouw, P. (2001). The rural non-farm sector: Issues and evidence from developing countries. Agricultural Economics, 26:1–23.

Lanjouw, J. O., & Lanjouw, P. (2001). The rural non-farm sector: issues and evidence from developing countries. Agricultural Economics, 1-23.

Lobell, D.B. & Field, C.B. (2007). Global scale climate-crop yield relationships and the impacts of recent warming. Environmental Research Letters, No. 2. 7 pp.

Maddison, D. (2006). The perception and or adaptation to climate change in Africa. CEEPA: In. Discussion Paper No. 10. Center for Environmental Economics and Policy in Africa. University of Pretoria, Pretoria, South Africa.

Mugi-Ngenga, E.W., Mucheru-Muna, M., Muqwe, J., Mugendi, D. (2016). Household's socioeconomic factors influencing the level of adaptation to climate variability in the dry zones of Eastern Kenya. Journal of Rural Studies, 43:49-60.

Padgham, Jon. (2009). Agricultural development under a changing climate: opportunities and challenges for adaptation. Joint departmental discussion paper; issue no. 1. Washington, DC: World Bank.

Pali, P., Miiro, R.Bashasha, B., Bulega, E., Deleve, R. (2002). Factors affecting the adoption potential of green manure and legume species in eastern Uganda. In: paper presented at the Annual Conference of the Soil Society of East Africa, Mbale, Uganda.

Reardon, T., Berdegué, J., Barrett, C. B., & Stamoulis, K. (2006). Household Income Diversification into Rural Nonfarm Activities. In S. Haggblade, P. Hazell, & T. Reardon, Transforming the Rural Nonfarm Economy. Baltimore: Johns Hopkins University Press.

Reardon, T., Delgado, C. and Matlon, P. (1992). Determinants and effects of income diversification amongst farm households in Burkina Faso. The Journal of Development Studies, 28:264–296.

Rosegrant, M., Cai, X., Cline, S. and Nakagawa, N. (2002). The Role of Rainfed Agriculture in the Future of Global Food Production. EPTD Discussion Paper N. 90, International Food Policy Research Institute 2033 K Street, N.W. Washington, D.C. 20006 U.S.A.

Rurinda, J., Mapfumo, P., van Wijik, M., Mtambanengwe, F., Rufino, M., Chikowo, R., Giller, K. (2014). Sources of vulnerability to a variable and changing climate among smallholder households in eastern Zimbabwe: a participatory analysis. Climate and Risk Management, 3:65-78.

Stern N. (2006). The economics of climate change: the Stern Review. H.M. Treasury, UK.

Tompkins, E. L., and H. Eakin. (2012). Managing private and public adaptation to climate change.

Global Environmental Change 22(1):3-11.

Tompkins, L.E., Eakin, H. (2012). Managing public and private adaptation to climate change. Global Environmental Change, 22:3-11.

Turner et al. 2003. A framework for vulnerability analysis in sustainability science. Proceedings of National Academy of Science, 100(14): 8074-8079.

Vitale, J. D., Godsey, C., Edwards, J. and Taylor, R. (2011). The adoption of conservation tillage practices in Oklahoma: Findings from a producer survey. Journal of Soil and Water Conservation, 66:250–264.

Wuepper, D., Ayenew, Y.H. and Sauer, J. (2017). Social Capital, Income Diversification and Climate Change Adaptation: Panel Data Evidence from Rural Ethiopia. Journal of Agricultural Economics, doi: 10.1111/1477-9552.1223.

Zia, M.S., Aslam, M., Nizami, M.I., Ali, A., Saeed, Z. (1996). Rainfed agriculture: problems and their management. Pakistan Journal of Soil Sciences, 11(1-2):164-171.

b. Identification of shifts in cropping patterns under 2ºC scenario

Introduction

By 2050, we will need to sustainably increase our food production to feed more than 9 billion people as well as providing economic opportunities in both rural and urban communities. Presently our agriculture is falling far short of these goals. An unprecedented systemic transformation is needed at a speed and scale to meet the current and the future challenges of food security. To achieve the targeted food production through sustainable agriculture, adaptation to climate change and transformation without depleting natural resources is needed. Over the years an increased prevalence of extreme events and unpredictability of weather patterns is convincing us to believe that, climate change is significantly impacting our agricultural systems and food security.

For last two decades in Pakistan, there has been no improvement in yield of major crops seasons may be attributed to climate variability and shifting of growing seasons, cultivation of crops in areas not suitable for those crops (e.g. rice crop in area suitable for cotton), time series declining water availability, gradual changes in soil nutrient status, lack of true to type cultivars etc. Considering rapid changes in land and water resources of the country and climate change over the past two decades, we need adaptation strategies to maintain as well as enhance our agricultural productivity sustainably that can ensure national food security. Climate is a prime factor that exerts major influence on vegetation, soil health and water resources and is likely to upsurge the vulnerability of agricultural systems by increasing temperature, changes in rainfall patterns, and more frequent extreme weather events in the world. FAO (2008) stated that climate change will affect food security through its impacts on all components of global, national and local food systems. There is an overwhelming report that climate change will bring both impacts and opportunities with respect to crop production. For example, the temperature higher than optimum negatively influences wheat crop and a decline in wheat yield is recorded with an increase of 1°C average seasonal temperature. On the other hand, increased concentration of CO_2 in the atmosphere is also attributed towards an increase in crop yield. Therefore, crop production is most important aspect of the food systems impacted by climate change and it is very pertinent to look at how climatic change would affect cropping patterns.

Many of the small-scale farmers in Pakistan lack knowledge about potential options for adapting their production systems and also has limited risk-taking capacity. Moreover, our agriculture systems are not cohesive, in which case climate variability can be more devastating for such systems. Only by devising and implementing appropriate adaptation measures will it be possible to ensure food security and sustainability.

There is explicit change in weather pattern of Pakistan. These changes have been amplified for the last decades due to more emission of greenhouse gasses. Mean temperature is increasing by 0.2 to 0.6°C per decade in Pakistan (AgMIP-2016) and night temperature is increasing more than day temperature. Climate change and variability has severe impact on crop production and could also be the reason for shift in cropping system in different regions of the Punjab province. Projected changes are expected to have a negative impact on yield of crops as well in Pakistan. The increase in night temperature is more detrimental for agricultural crops. Temperature and rainfall patterns affect the crop choice in different zones and for sustainable agricultural production, current spatial and temporal changes in rainfall and temperature need to be considered.

The conceptual framework presented below provides an overview of our study. The objective of this study is to take cognizance of the emerging impacts of climate change on cropping patterns in the country and provide an overall policy framework and guidelines for a comprehensive plan of action.

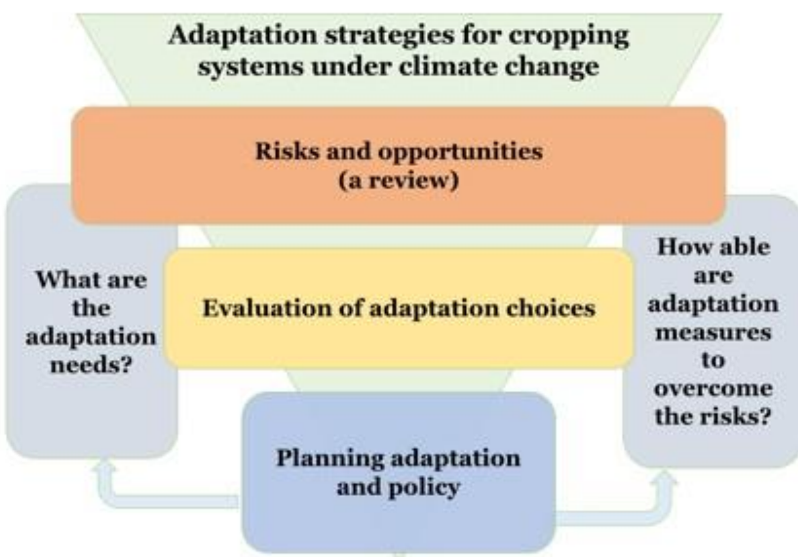

Figure 1: Conceptual framework

Methodology

The study is envisioned to work on developing crop suitability maps to define cropping patterns for changing climate. The agro-ecological zones (AEZs) methodology of FAO will be utilized to propose best fit cropping systems according to the resource availability, climatic conditions and economic benefits. Following information will be used to map the latest cropping pattern in the country.

- The Precipitation and Potential Evapotranspiration derived soil moisture index and Agro-

  Climatic Zones
- The quantity and quality of total available water (including surface water and groundwater)
- The soil characteristics, including texture, organic matter and chemical properties
- Land-use characteristics and topography
- Crop Norms for more than 60 existing and future crops
- Economic suitability zones for the produce

The representative concentration pathways (RCPs) responsible for a projected 2^{o}C rise in temperature will be used in climate models to provide the data for corresponding climate variables. The projected climate data will be used in AEZs to develop crop suitability maps. Still there is a need for better yield estimates in different 'suitable' climatic conditions for growing crops and a more detailed economics studies to evaluate comparative advantage to different crops in different zones to come up with crop clusters. A comprehensive review of crop modeling studies in Pakistan can provide insight into the yield trends with changing climate scenario.

As successful adoption of cropping system and crops in a specified region heavily depends on critical analysis and assessment of Agro-climatic normal and available resources for crop production. Therefore, identification of shift in cropping patterns with climate change will reveal an enormous potential for crop diversification as well as sustainably enhanced crop productivity.

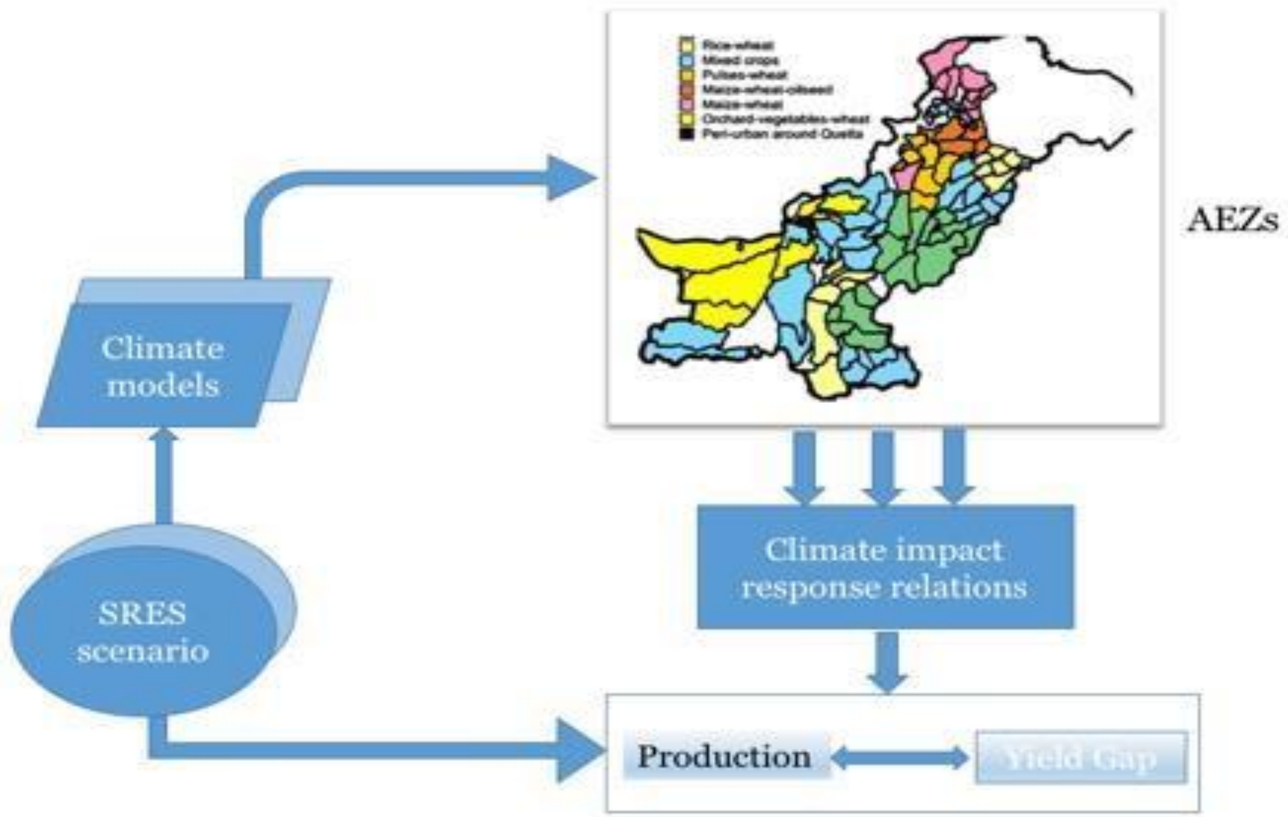

Figure 2: Methodological framework

The range of local weather conditions that has shaped the current structure of domestic agricultural production, however, is changing in response to broad shifts in general climatic conditions across the country and around the world. General climatic conditions have adjusted slowly throughout the 20th century, with global average temperature increasing 1.3 degrees

Fahrenheit (°F) (IPCC, 2007). As atmospheric concentrations of carbon dioxide (CO2) have increased, the rate of temperature increase appears to be accelerating, and recent climate models predict further warming trends over time that may have a significant impact on local temperature and precipitation patterns.

Increasing Temperatures

Climate is a prime factor that exerts a major influence on vegetation, soil health, and water resources. Changing climate is likely to elevate the vulnerability of agricultural systems (Rosenzweig et al., 2014) by increasing temperature, changes in rainfall patterns, and more frequent extreme weather events in the world (IPCC, 2014). There is an explicit change in the weather patterns in Pakistan (Ahmad et al., 2015). These changes have been amplified for the last decades due to rising emission of greenhouse gasses. Mean temperature has been increasing by 0.2 to 0.6°C per decade (AgMIP-2016) and night temperatures have increased more than day temperatures. Climate change and variability have impacted crop production and could also be the reason for the shift in cropping systems in some regions of Punjab province.

The impact of increasing temperatures on crop growth will depend on how climate change shifts local temperatures relative to the optimal temperature range for the crop varieties growing in that region. Research suggests that crops may be particularly sensitive to temperature extremes during the reproductive phase, when pollen viability and seed setting are vulnerable to high temperatures (USCCSP, 2008). Higher average temperatures may also result in accelerated crop maturity, as optimal air temperatures for growth occur earlier in the season, which can result in less seasonal growth and lower yield potential. Temperature also has an important effect on crop water demand. Increased crop water requirements under a warming climate may place greater demands on available soil moisture and irrigation water supplies. Actual water demand will depend on other climatic factors as well; including field humidity and shifts in solar radiation caused by changing cloud cover and aerosol concentrations.

Existing Cropping Patterns in Pakistan

Pakistan Agricultural Research Council (PARC) divided Pakistan into ten distinct zones based on physiography, climate, land use and water availability in 1980 (Figure 3). However due to changing climate and an increased pressure on natural resources from population growth and the recent socio-economic situations demands an effort to delineate the AEZs based on physiography, climate, agriculture, land use, water availability, and existing cropping patterns bounded within common administration boundaries.

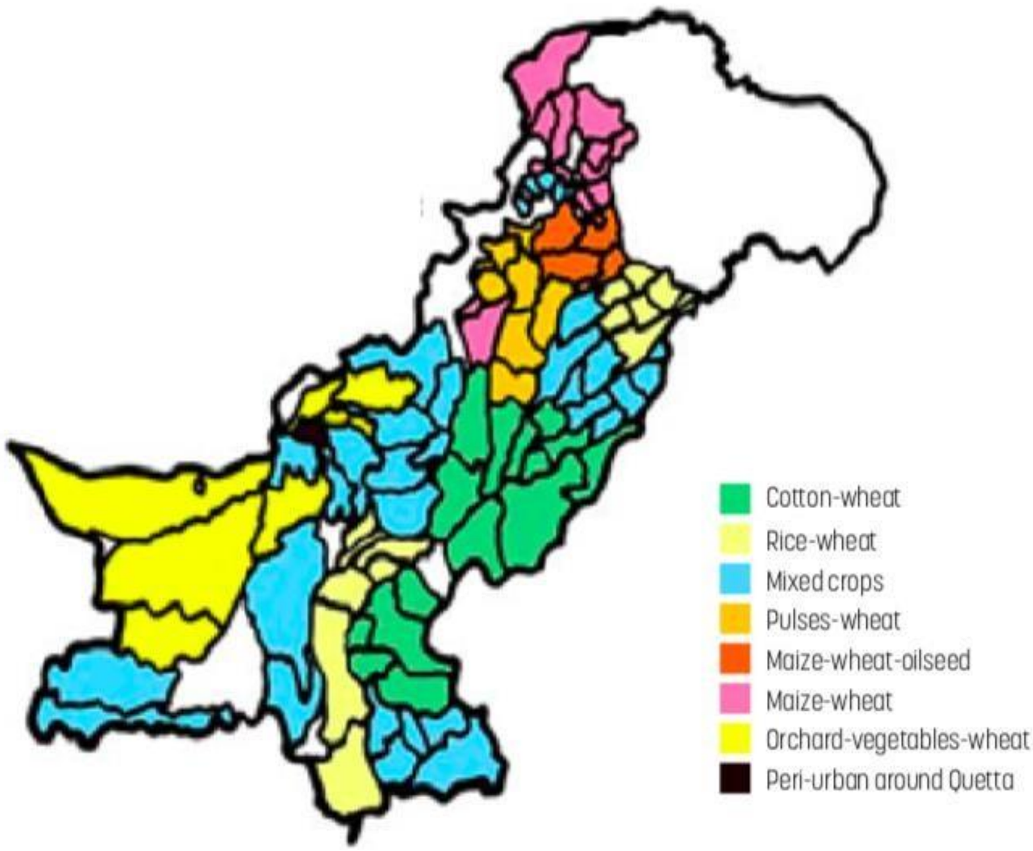

Figure 3: AEZs in Pakistan

Cropping Patterns in Pakistan under $2°C$ rise in temperature

- Cotton-wheat

This cropping zone in Punjab is comprised of districts of Sahiwal, Pakpatan, Khanewal, Vehari, Multan, Lodhran, Bahawalnagar, Bahawalpur, and Rahim Yar Khan and it covers

Sothern part of Punjab that borders with India and province of Sindh (Figure 3). Cotton, wheat, rice, maze, sugar cane and potato are major crops along with some oil seeds, pulses and vegetables. In addition to that citrus, mangoes and guava orchards are also present in this zone. Irrigation from canals is the primary source of soil water. The rainfall in this region is very low in winters however, it receives good rainfall in monsoon season. The rainfall is expected to decrease further in $2°C$ warmed climate, especially in the spring season.

The heat stress during critical growth stages of crop production can significantly reduce crop yield as well as quality. Therefore, an increase in temperature can be catastrophic for both crops and vegetables. In future $2°C$ warm climate will have more dry days than present nevertheless, the agriculture in this region depends mainly on canal water, therefore, a major shift in cropping patterns is not expected.

- Rice-wheat

The districts of Sialkot, Gujrat, Gujranwala, Sheikhupura, Lahore, Kasur, Narowal, Mandi Bahauddin, and Hafizabad are rice-wheat region of Pakistan (Figure 3). Canal water supplemented by tube wells provide irrigation for the crops in this region. Rice and Wheat are major and, Jawar, Bajra, Mash, Moong, Masoor, Gram, Maize, Tobacco, Oil Seeds are minor crops in this region. The GCM simulations suggest an increase in both maximum and minimum temperature in all months under $2°C$ scenario and overall an increase in the likelihood of extreme events in maximum temperature is expected in spring and autumn seasons. And in case of dry conditions likelihood of extreme daytime temperature increases.

The Comparison of yearly cumulative precipitation in the baseline period and future warming periods indicates that late winter and spring will turn drier in the warm scenario. Early monsoon will receive less rainfall whereas late monsoon will receive more rainfall dominated by extreme intensity events that may lead to flooding and inundation. Wet summer are expected to lead to wet winters. With an increase in $2°C$ in mean annual temperature of Pakistan this zone is expected to be warmer. However, the presence of extreme events on the both ends of temperature's probability distribution (above 75th percentile and below 25th percentile) indicates an oscillation of climate between prolonged hot dry and relatively shorter cool wet cycles on inter-annual to inter-decadal scales. In addition to this, since, late winter and spring are expected to be warmer and dryer, therefore, it may affect sowing of Kharif crops (sown in spring and harvested in autumn) due to limited availability of soil moisture, on the other hand, the Rabi (sown in autumn and harvested in spring) may be affected by an increase in late monsoon precipitation especially if it is causing flood and inundation. Overall, annually cumulative precipitation is expected to increase with higher variability coupled with prolonged dry spells terminated with intermittent short intense rainy periods.

- Mixed-crops

The mixed cropping region in Punjab is comprised of districts of Sargodha, Khushab, Jhang, Faisalabad, Toba Tek Singh and Okara. In baseline periods, this zone is dominated by mild cold days and cold nights and they are set to become warmer with projected increase of 2°C temperature.

Annual frequency of warm and hot days along with warm uneasy nights is expected to increase with decrease in that of wet days. However, the intensity of individual rainfall events is expected to increase in future warmer period, especially in summer and autumn season. Late winter and spring season cumulative precipitation is likely to decrease in magnitude and monsoon is likely to be weaken in early season, while being strong and intense in late season that may increase the risk of flooding. On the other hand, increase in autumn season rainfall may have a positive effect on fall (Rabi) crops as soil would be moister (in case there is no flood).

- Pulses-wheat

The Pulses-wheat region comprise districts of Dera Ghazi Khan, Rajanpur, Muzaffargarh, Layyah, Mianwali, Bhakkar, and Dera Ismail Khan. This region is situated on the banks of River Indus and the rivers of Punjab merge together in the south of this region. Climate of this region is dry and hot in summer with little rainfall, winter is relatively cold.

In baseline period the annual frequency of extreme hot days was little more than 50 days that would be increased to 3 months in the future warmer period. It may damage Rabi crop. The monthly accumulated precipitation is expected to decrease in spring and monsoon season with the projected increase of 2°C temperature. This situation may reduce the effective rainfall available for growing crops. The spring precipitation is expected to decrease in future that will cause more dryness and will increase the chances of heatwave conditions.

Summary and conclusions

The climate-related impacts on cropping patterns are uncertain. We expect that if farmers have access to a broad selection of crop varieties, they are likely to select varieties that most suited for the local growing conditions. That means cropping pattern change will depend on the availability of crop varieties and cultivars that will adapt to climate change; altered growing periods, drought and other stresses.

References

Ahmad, I., Ambreen, R., Sun, Z., Deng, W. *Winter-Spring Precipitation Variability in Pakistan* Am. J. *Climate Change*, 4 (1) (2015), pp. 115-139

IPCC. 2014. *Climate Change 2014. Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., Khabarov, N. 2014. *Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison.* Proceedings of the National Academy of Sciences, 111(9), 3268-3273.