# Climate change farm based autonomous adaptation measures and its impact on wheat crop productivity in Punjab, Pakistan

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**Research Article**

**Keywords:** Wheat farmers, Climate risks, Probit model, Punjab, Pakistan

**Posted Date:** February 9th, 2022

**DOI:** https://doi.org/10.21203/rs.3.rs-1214354/v1

# Abstract

Climate induced hazards has increased production threats to agriculture where such environmental risks can significantly reduced by adapting adaptation measures. In farm based adaptation measures specifically the autonomous adaptation aspect has not properly focused particularly in developing countries like Pakistan. This study attempted to investigate on-farm autonomous adaptation (OFAA) measures of wheat farmers to climate change and estimate its impact on wheat yield and total return. This research work used the data of 480 wheat farmer from production based six categorized higher vulnerable districts of Punjab, Pakistan. Probit model was employed to examine adaptation decisions determinants of farmers and Propensity Score Matching used for to investigate the impact of OFAA practices on outcomes of wheat crop. Estimates indicated as wheat farmers to reduce the unfavorable effects of climate change have applied different OFAA strategies such as seed varieties changing, fertilizer management, variations in cultivation dates and management of supplementary irrigated water. Probit model estimates illustrated as climate information access, credit access, ownership of land, off-farm income and ownership of tubewell considered significant determinants regarding adaptation decisions of farmers. Estimates of propensity score matching indicated as farmers those applied almost one OFAA strategy obtained 310kg per hectares higher wheat yield as US$82.75 per hectares return rather than those not applied any adaptation strategies. Adapter wheat farmers applied multiple adaptation strategies obtained higher yield and return rather than adapter farmers used limited adaptation strategies. Results imply as in developing sustainable farmers livelihood, adequate food production, reducing crops variability and climate change adverse impacts it is mandatory to applications of OFAA measures. The study also elaborated as for developing farm-level adaptation there is significant role of climate information, farmers schooling, access of credit and adequate irrigation.


# 1. Introduction

Climate change frequent dynamics in the couple of decades has increased severity and incidence of natural disasters such as flood, landslides, drought, cyclones and earthquakes (Teo et al., 2018; Huong et al., 2019; Martins and Gasalla, 2020; Ahmad and Afzal, 2021). In 21st century, adverse impacts of climate change caused major threats to socioeconomic development which particularly and severely affected the livelihood of rural farmer population (Eckstein et al., 2018; Nerrini et al., 2019; Kreft et al., 2021). Rising global temperature and weather pattern variation due to climate change caused severe losses to overall economic sectors whereas agricultural was hardest hit (Crane et al., 2017; Rasiah et al., 2018; Hussain et al., 2019). In global scenario, world's majority population livelihood directly depends and gains nutritional food from agriculture (Ahmad et al., 2019; Shah et al., 2020) whereas this sector confronted with climatic threats which has alarming implications of global poverty alleviation and food security (Daniell et al., 2017; Amare and Simane, 2018; Ahmad and Afzal, 2020). Climatic threats globally affected agriculture whereas South Asian region considered higher vulnerable in such perspective because of dense population, pitiable adaptive capacities and agro-based economies (Bokhari et al., 2018; Eckstein et al., 2019; Martins and Gasalla, 2020; Hoq et al., 2021). South Asian region is also recognized the super market of natural hazards due to its consecutive occurrence and higher severity which specifically caused destruction of crops and infrastructure (Teo et al., 2018; Ahmad et al., 2019 Kreft et al., 2021). It is forecasted as continuity in rising sequence of temperature will reduce cereal production 10% till year 2100 particularly in South Asia region (Aggarwal and Sivakumar, 2010; IPCC, 2019; Khan et al., 2020).

In global perspective, Pakistan ranked world 5th climate change affected country due to significant variability of climate change (Eckstein et al., 2018; Kreft et al., 2021). In Pakistan it is estimated to raise 0.5$^{\circ}$C annually from 1960 which approaches to 3$^{\circ}$C till year 2100 (Khatri-Chhetri et al., 2019; Khan et al., 2021) as such consecutive raising temperature has increased the occurrence of climate induced hazards such as erratic rains, cropping season variations, biological hazards, droughts and floods (Ahmad and Afzal, 2020; Shah et al., 2020). In the couple of decades Pakistan faced sequence of four deadly floods 2010 to 2014 and from 1990 to 2000 series of severe droughts (PBS, 2017; NDMA, 2019; Ahmad and Afzal, 2021) which consequently raised biological risks and faming communities livelihood become more vulnerable (Shah et al., 2018; Jawid et al., 2019). In last twenty years, the current locust insect's outbreak devastated the country crops which mostly related to regional unpredictability of precipitation and temperature (BOS Punjab, 2020; PBS, 2021). It is estimated as in Pakistan future rainfall change -0.89 mm and temperature will raise +0.24$^{\circ}$C per decade and climatic parameters cause to significantly variation in current climate (WHO, 2013; Islam and Ghosh, 2021). In the scenario of Punjab province climate change per decade projection estimated as declining in rainfall -3.5mm and rising in temperature +0.05$^{\circ}$C causes to increase the large length vulnerabilities to agricultural crops (PMD, 2018; Ahmad et al., 2019; PBS, 2020).

Pakistan an agrarian economy where almost 70% population depends on agriculture for their livelihood it provides employment to 38.5% labor force and shares 19.2% GDP of the country (PBS, 2021). During the couple of decades because of frequent climatic variations country faced higher yield losses particularly the cereal crops which subsequently raised emerging issue of food security in the country (Shah et al., 2020; PBS, 2020). In cereal crops, wheat is main cereal crop of the country which provides staple food diet to population (Ahmad et al., 2019; PBS, 2020) as Pakistan ranked 8th major wheat producer country in global perspective (FAO, 2019). Wheat crop contributes 1.8% of GDP and 9.2% in agriculture value added of the country (PBS, 2020). In crop year of 2020, wheat was cultivated in 8,805 thousands hectares and produced 25.248 million tonnes with the yields of 2867 kg per hectares which is relatively lower as other agrarian wheat producing countries (PBS, 2021). In the last couple of decades, Pakistan faced repeated environmental variations such as drought in winter season and climate induced diseases, erratic rains and floods in summer season caused severe losses of crops production (Ahmad et al., 2019; PMD, 2019; Shah et al., 2020). Wheat yield is consecutively declining in Pakistan due to severe climate induced threats such as hail, erratic rain and storm in summer harvesting season and drought in winter season (Abid et al., 2015; Ahmad and Afzal, 2020).

Climate change adaptation is considered as varying farming practices regarding to projected or existing environmental variability to evading possible risks (Rahman and Hickey, 2018; Abid et al., 2020). Adaptation can categorized according to type and nature whereas planned and autonomous are most significant types regarding adaptation measure (Khanal et al., 2018; Khan et al., 2020; Ahmad and Afzal, 2021). Autonomous adaptation deals as farmer responses at farm level in which farmer regarding their considerations and pattern of local climate adapt farm based climate induced adaptation measures (Mersha and van Laerhoven, 2018; Ahmad et al., 2019). Planned adaptation compact with government led involvement wherever State based institutions having the mechanism for designing and application of climate based adaptation measures (Rahman and Hickey, 2019). In the empirical based scenario, planned adaptations have long term significance whereas higher significance about effective application has measured regarding autonomous adaptation where no appropriate facilitation from institutions and government (Leclere et al., 2013; Khanal et al., 2018).

In literature, climate change and agriculture aspect more particularly focused during the couple of decades in global scenario with specifying the climate change mitigation (McCarl and Schneider, 2001; Metz et al., 2007; Duarte et a., 2013; Kabisch et al., 2016; Demski et al., 2017; Lucena et al., 2018; Solan et al., 2020), climate change assessment (Seo and Mendelsohn, 2008; Adger et al., 2009; Iglesias et al., 2011; Zhongming et al., 2012; Pandey et al., 2016; Nakashima and Krupnik, 2018; Nakashima et al., 2018; Abid et al., 2019; Arif et al., 2020; Giri et al., 2020) and climate change adaptation measures (Schlenker and Lobell, 2010; Locatelli et al., 2015; McCarl et al., 2016; Chalise and Naranpanawa,2016; Vermeulen et al., 2018; Day et al., 2019; Cui, 2020; Jørgensen et al., 2020; Chen and Gong, 2021). Some studies in literature also focused climate change adaptation application in various aspects such as risk management through ex-ante and ex-post adaptation (Hou et al., 2018; Abid et al., 2020) where few studies discussed nature of adaptation as planned adaptation and autonomous adaptation (Forsyth and Evans, 2013; Bawakyillenuo et al., 2016; Mersha and van Laerhoven, 2018; Rahman and Hickey, 2019). In literature regarding to higher climate vulnerable country like Pakistan limited research work exists with various aspects such as climatic disaster risk reduction (Shah et al., 2020), climate vulnerability (Khan et al., 2020) and assessment of risk and models of climate risk assessment (Siddiqui et al., 2012; Abid et al., 2016; Ali et al., 2017; Ahmad et al., 2020) whereas no research work in scenario of Pakistan have not addressed the aspect of autonomous adaptation application for local poverty reduction and food security. In developing country like Pakistan where State based institutions are not capable to support farming communities, farming community least resilient and agriculture higher susceptible to climate variation adaptation on farm level and its usefulness have higher significance such aspect need to address. In addressing this research gap this research work paying attention (a) to investigate wheat farmer's on-farm climate change autonomous adaptation strategies (b) to estimate impact of adaptation on wheat crop yield and total return (c) to investigate its applications for local poverty reduction and food security. This study is subdivided in to four segments as introduction illustrated in first segment, second segment discussed material and method. Third segment of the study highlighted results and discussion whereas last segment elaborated the conclusion and suggestions.

# 2. Material And Method

## 2.1 Selection of study area

Punjab province is publicly recognized the land of five rivers, augmented with fertile lands and located in central region of the country (GOP, 2021). Punjab among four provinces of the country more preferably focused for this research because of several considerable bases. Firstly, Punjab is foremost agricultural GDP contributor 52% and represents 53% population of the country (PBS, 2020). Secondly, Punjab by producing ¾ of country's cereals production is known food basket of the country (GOP, 2021). Thirdly, Punjab produces 77% wheat of the country (BOS Punjab, 2020) whereas currently facing consecutive and significant yield reduction owing to induced factors of climate change. Lastly, wheat production is more susceptible in the region due to consecutive increase in erratic rainfall, rising temperature and frequent hailstorms in recent decades (PBS, 2021). This scenario has severe threat for livelihood of millions of wheat farmers' households and food security relying for their employment and nutrition in the region. Kharif and Rabi are two major cropping seasons comprising with major and minor crops (BOS Punjab, 2019). Based on share of province in wheat production six districts were chosen with various wheat production based categorizations. In scenario of wheat production, Dera Ghazi Khan and Layyah from low wheat producing districts, Muzaffargarh and Vehari from medium while Rahim Yar Khan and Bahawalnagar from high wheat producing districts were purposively chosen for the study as indicated in figure 1(BOS Punjab, 2021). In the study, all six selected districts, risk variations experience, socioeconomic, geographical, climatic and structural characteristics were documented. In provincial environment climatic variation were estimated as cold in winter and hot in summer having the average temperature of 33.9˚C in summer and average temperature of 8.7˚C in winter (PMD, 2019). In Punjab, rainfall disperse pattern was estimated where 68% erratic and routine rainfall mostly expected in monsoon season (PMD, 2019; BOS Punjab, 2020). Major cash (sugarcane and cotton) and cereals crops (wheat, rice and maize) major share is produced in Punjab province which severely affected from climate induced factors (PBS, 2021).

[Figure 1]

## 2.2 Data collection and sampling framework

In sample selection of wheat growers from the study area multistage sampling method was used by involving random selection and stratified approach. In the first stage, Punjab more preferably considered because of higher wheat production province in the country. In the second stage, in using the stratified sampling approach six districts were chosen according to categorized low, medium and high wheat producing areas of Punjab. In particular, districts were categorized in province such as low wheat producing zone (below 600,000 tonnes), medium wheat producing zone (600,000 to 900,000 tonnes) and high wheat producing zone (above 900,000tonnes). In each categorized wheat production zone, two districts were randomly selected in the third stage. In fourth stage, two tehsils from each district were randomly chosen and from each tehsil two union councils were randomly chosen. In the last stage, from each union council two villages were randomly chosen and ten wheat farmers were randomly preferred for data collection comprising 480 total wheat farmer from study area. From each province eighty wheat farmers were interviewed as sampling framework illustrated in Table 1.

[Table 1]

In the study area, a well-structured questionnaire was applied for face to face interview and data collection from sample household's wheat farmers. To ensuring the accuracy and relevancy of the data a pre-tested survey was conducted prior to collecting the data from study area. Farmers farming practices, socioeconomic characteristics, farm outcomes related to production outcomes and adaptation practices were main feathers included in the questionnaire. Author himself and four enumerators the students of COMSATS University Vehari prior trained for data collection in the study area. Data collection regarding farmer's response about wheat crop outcomes and adaptation practices and data collected from July 2020 to October 2020. In the scenario of study objectives and usage of collected data farmers were well informed and motivated to participate in data collection with accuracy of information. Farmers involve themselves warmly about data collection questionnaire and 27 participants refused to take part which were replaced to others farmers from study area.

## 2.3 Empirical framework

## 2.3.1 OFAA evaluation impact on wheat productivity

Crop return and production is feasible to increase through using the effective adaptation measures. In estimating the adaptation impact on wheat production, wheat farmers were firstly categorized in to two types' non-adapter and adapter farmers. Non-adapter were considered those farmers who have not applied any OFAA adaptation measure and adapter those who at least applied single adaptation measure for wheat crop to reduce climate change severity. In such estimation, in the Table 3 there was conducted the mean contrast for revealing significant difference about return and yield of wheat crop between non-adapter and adaptation measures adapter farmers. In the meantime, attributes of farm related and socioeconomic characteristics also varieties in non-adapter and adapter wheat farmers as adapter farmers more access of institutions services and resources rather than others. On the basis of selection biased likelihood such type of empirical results are not adequate to measure the impact of adaptation on wheat return and yield (Abid et al., 2016; Ali et al., 2017; Ahmad et al., 2019). Consequently, it considered critical to undertake the matter selection bias to accurately measure adaptation impact on wheat return and yield.

In literature, selection bias issue tried to minimize in mostly studies tackled with application of different methods such as endogenous switching regression (ESR), approach of instrumental variable (IV) and two-step Heckman test models (Khan et al., 2018; Ahmad and Afzal, 2020). Furthermore, such methods have some limitations in applications such as Heckman method addresses only the internal factor of normal distribution whereas endogenous switching regression (ESR) and approach of instrumental variable (IV) need to applicable instrumental variables about treatment equation to measuring the influence as considered the demanding to identify in the estimation investigation (Heckman and Vytlacil, 2007; Abid et al., 2016). In considering the significance and nature of this study, propensity score matching (PSM) method is applied in this study for estimating the impact of OFAA on wheat yield.

## 2.3.2 Propensity score matching (PSM)

In resolving the issue of selection bias in the model, method of propensity score matching is mostly applied in most of the studies. Concerning the limitations of functional form, unobserved attributes of normal distribution and for treatment equation instrumental variables in the methods of instrumental variable (IV), Heckman and ordinary least square (OLS) whereas propensity score matching (PSM) method has no such limit (Caliendo and Kopeinig, 2008; Rubin, 2015;Ahmad et al., 2019). In the method of propensity score matching on the basis of treatment variable usage and adoption pattern sample is categorized in to two types such adapter as treatment group and non-adapter as controlled group (Dehejia and Wahba, 2002). This study illustrated as those farmers adopted at least single adaption measure indicated as treatment variable (adapter) whereas farmers those not used any adaptation measure elaborated as controlled group (non-adapters). Observed socioeconomic factors are required in the method of propensity score matching (PSM) to match control group and the treatment for estimating the treatment casual impact.

Taking into consideration the pre adaption in scenario of visible threat, the method of propensity score matching can be observed as provisional probability about adaptation of farmer to climate change. Related to the conditional independence assumption the method of propensity score matching constructs the statistical contrasts groups through matching adapter and non-adapter related to their forecasted probabilities of adoption to climate change (Frolich, 2007; Caliendo and Kopeinig, 2008; Froehlich and Al-Saidi, 2017). Propensity score matching (PSM) equation as illustrated below

$$p(X_{ik}) = Pr.\left[U_i = 1 \mid X_{ik}\right] (1)$$

In the above equation propensity score elaborated as p whereas $X_{ik}$ indicated the observable attributes, whereas pr as adaptation probability to climate change $U_i$. There is similar conditional to distribution regarding to non-adapter and adapter in the model of propensity score matching (Frolich, 2007;Thavaneswaran and Lix, 2008).

In measuring the treatment impact on variables outcomes propensity score matching estimation engaged in to five stages. In the first stage, related to theoretical assumptions initially selected the list of observable covariates (socioeconomic threats of farmers) for pre-testing. Secondly, propensity score or probabilities are estimated through observable covariates of regressing related to outcome variables (adaptation determinants) (Ali and Abdulai, 2010). In the third stage, matching method is applied to anticipated propensity score matching of non-adapter and adapter (Kassie et al., 2011). Treatment casual effect (adaptation) is estimated the variables outcome (wheat yield) in the fourth stage (Rubin, 2001). In the last stage, propensity score evaluation estimation is finalized to check estimation accuracy (Frolich, 2007; Caliendo and Kopeinig, 2008).

## 2.3.3 Observable covariates selection

In agriculture adaptation decisions of farmers are mostly affected by their socioeconomic feathers as empirically investigated in multiple studies (Bryan et al., 2013; Alam et al., 2017; Khanal et al., 2018). Regarding the evidence in literature, data availability and nature of study variables in number fifteen were chosen as covariates observable hypothesized regarding farmers decision influence related to climate change strategies adoption. Attributes of institutional services, farm status, farmers socioeconomic characteristics were chosen as observable covariates. In Table 2, list with details of observable covariates of farmers, with measurement unit and description has elaborated. Explanatory variables impact on adaptation decisions with expected direction indicated with the associated sign.

[Table 2]

## 2.3.4 Wheat yield adaptation casual impact

Adaptation (treatment) casual impact on wheat crop yield is estimated on the treated average treatment effect (ATE) and average treatment effect on treated (ATT). Average treatment effect (ATE) reports on average treatment effect on variable outcome in on the whole population whereas ATT refers influence on treatment related to outcome variables among respondents that were treated (treatment matched and controlled respondents). The ATE impact can be reported as below equation

$$t_{Ui=1} = E\left(t \setminus U_i = 1\right) = E\left(Y_1 \setminus U_i = 1\right) - \left(Y_2 \setminus U_I = 2\right) (2)$$

In above equation, in population average treatment effect (ATE) indicated as t, control group as $Y_2$ and treatment as $Y_1$ which is this study related to non-adapter and adapter wheat growers. In such scenario as indicated prior ATE, $E(t/U_i=1)$ do not directly observed through estimating difference $E(Y_1/U_i=1) - (Y_2/U_i=2)$ as estimates may be biased. Furthermore, ATT can be observed that illustrates the precise estimates after contrasting the treatment and controlled groups. Average treatment effect on treated (ATT) as illustrated in the equation below

$$T = E\left\{Y_1 - Y_2 \mid U_i = 1\right\} = E E\left\{Y_1 - Y_2 \mid U_i = 1, p(X)\right\} = E\left[E\left\{\left(Y_2 \mid U_i = 1, p(X)\right\} - E\left\{Y_2 \mid U_i = 2, p(X)\right\} \mid U_i = 2\right] (3)$$

In above equation, ATT reported as notion T whereas p(X) as after calculated propensity score. In sequence of calculating the p-score, respondents were chosen from control and treatment group on the basis of their alike visible traits by applying the procedure of nearest neighbor matching (NNM). Non-adapters and adapters considered the partners this method through similarities matching in socioeconomic profile of farmers. Lastly, respondents separate groups are generated (unmatched and matched). Furthermore, outcome difference is subtracted by ATT in the matched groups which show the bias section minimal chances (Rubin, 2001; Dehejia and Wahba, 2002).

# 3. Results And Discussion

## 3.1 Farmers socioeconomic characteristics descriptive statistics

Climate change strategies non-adapter, adapter differences and pooled sample farm base and socioeconomic characteristics mean values illustrated in Table 3. In study area majority of wheat farmers 78%(374) adopted OFAA climate change adaptation measures whereas adapter were relatively younger (45 years), higher schooling (8years) rather than average schooling (7years) and age (48 years) in sample area. Adapter farmers have higher household size (8members) and primary occupation of agriculture (88%) rather than average household size (7members) and primary occupation (75%) in study area. Almost 49% non-adapter farmer’s considered agriculture primary source of family income so less conscious to manage adaptation rather than adapter farmer. In study area, average land holding (7acres) and 90% farmers having land ownership whereas adapter farmers have higher land holding (9acres) and 97% were owner of land illustrating as adapter have higher ownership and holding land than non-adapter farmers. In study area, limited irrigation 13.7% feasible with canal water whereas 86.3% managed by farmer through tubewell because of that majority 90% of adapter farmers having ownership of tubewell rather than 32% non-adapter farmers. These illustrations indicated as water supply enhances the farmer’s capacity of managing climate risks of wheat crop such as in winter shortage of water is managed through tubewell water supply.

[Table 3]

In study area, adapter farmers considered more resourceful regarding assets as holding average 8animals and farm income almost 49 thousands monthly higher than non-adapter with livestock (4.32 animals) and 24 thousands monthly income. Climate information access, advisory services and credit access considered significant variables regarding institutional services in the study area. Information accessed through formal and informal sources whereas farm based formal sources organizations/institutions by private and public considered more feasible in this study. Estimates illustrated as farmers have higher access of climate change information 60% and advisory services 57% rather than credit access 36% because of higher advancements in technologies such as mobile phones and internet access. Mostly organizations and institutions provide advisory services and climate information through SMS/WhatsApp applications which becomes more feasible for farmers (Khan et al., 2020; Ahmad and Afzal, 2021). These results illustrated as adapter farmers as contrast to non-adapter farmers more resourceful regarding assets because of higher more access of information and higher income due to more consideration regarding climate change adaptations and access higher yield of crops (Zhai et al., 2018).

## 3.2 Farmer adapted OFAA strategies

In the study area to overcoming the climate change risks farmers applied multiple OFAA adaptation strategies as particularly indicated in the figure 2. Overall wheat farmers more specifically focused OFAA seed variety changing (73%), managing fertilizer (67%), strategies supplementary irrigation (64%), irrigation time changing (61%), variation of planting and harvesting (56%) and resizing plots (51%). Such estimate illustrated as majority of wheat farmers prioritized changing in usage of seed varieties having water resistance and weather efficient to coping climate change severe effects and less vulnerable to environmental variation. These climate smart varieties having higher resistance to climate severity and induced insects more feasible measure to higher wheat yield as these finding are consistent to studies of Arunrat et al., (2017), Ahmad et al., (2019) and Sertse et al., (2021). Managing fertilizer another significant measure from study area farmers because adequate and timely provision of fertilizer causes to enhances resistance of wheat crop regarding climate variation and appropriate growth of wheat crop as finding is in line with the study of Ahmad and Afzal, (2020). Adequate supply of supplementary irrigation through tubewell to wheat crop in winter season when canal water is not available for irrigation such adaptation measure causes to enhance wheat yield. These estimates are alike with the studies of Abid et al., (2016), Ahmad et al., 2019 and Shah et al., (2020).

[Figure 2]

Furthermore, irrigation variation is another application of water smart strategy consider to use for reducing water requirement of crop mostly indicated as avoid irrigation usage when climate conditions not feasible for irrigation to crop. Climate smart water strategy more significant measures regarding irrigation usage to crop as these findings are alike with the study of Ahmad et al., (2019). Wheat crop cultivation and harvesting altering strategy is mostly induced by local climate variation pattern. Local based climate-induced patterns based strategy of cultivation and harvesting of wheat crop common strategy measure mostly applied by local farmers as conclusions are consistent with research work of Alauddin and Sarker, (2014), Abid et al., (2016) and Khanal et al., (2018). Resizing plots considered the more feasible measure about climate based effects of water shortage. Extension of plots within the acres reported the resizing plots when cultivating various crops in the limited cultivated area whereas such practices causes to more labor cost, irrigation cost, issues of land leveling and time consuming as compared to large plot sizes. These conclusions are in contrast with the study of Arunrat et al., (2017) and Amare et al., (2018).

Farmers from higher and medium wheat production areas more preferably focused the changing crop varieties, managing fertilizer and supplementary irrigation climate smart adaptation strategies whereas low wheat production farmers preferred to plot resizing, changing irrigation time and harvesting and cultivation changing. Adapted based strategies measures of wheat farmers were classified in to four categorizes as higher adapter (applied>4 adaptation measures), medium adapter (applied 3 or 4 adaptation measures) small adapter (applied 2 adaptation measures) and non-adapter (not applied any adaptation measure) for assessing diversification application measures. Majority of farmers (34%) were higher adapter, (28%) medium adapter and (16%) small adapter as illustrated in figure 3 illustrating as majority of wheat farmers in the study area have applied multiple adaptation measures to climate change. Almost one-fifth (22%) wheat farmers in the study area not focused any climate-induced adaptation measure in the study area. Higher frequency of climate-induced non-adapter and small adapter was estimated in the low production region whereas majority of medium and high adapter farmers belong to high and medium wheat production region. These estimates indicated as in low yield districts farmers having limited diversification adaptations measures whereas higher diversification adaptation among wheat farmers was estimated in medium and high wheat yield production districts which alternately causes the yield differences in the various districts and regions.

[Figure 3]

## 3.3 Adaptation impact on wheat crop yield and return with cost-benefit analysis

Adapter and non-adapter wheat crop average outcomes comparison illustrated with major differences of wheat yield and return of total crop as indicated in Table 3. Significant variation regarding non-adapter and adapter estimated related to input cost that inspires to prerequisite the analysis of cost benefit. Moreover, for estimating the diversification adaptation impact on outcome of crop, comparison was estimated means of wheat yield, cost of total input, return of total crop and gains of total profit in four categorized farmers groups and generated the results. Wheat farmers were categorized in to four groups for estimating profitability across intensity of adaptation as such measure were taken for estimating adaptation profitability in the research work of Arfanuzzaman et al., (2021).

[Figure 4]

In study area among various types of climate induced strategies adapter farmers the mean (maund per acre) of wheat yield and total return illustrated in figure 4 and 5. Estimates indicated as wheat crop yield and total return per acre increased from small to medium and higher adapter because higher intensity of adaptation strategies increases yield of wheat production and total return. Remarkably, more prevalent increasing trend related to districts of higher production zone that is the reason of higher adaptive capacity to application multiple adaptation strategies. Another reason is that farmers in high yield region having higher financial resources so allocate additional financial resources for crop inputs. Additional resources allocation for farm inputs particularly based on adaptation of diversification causes ultimately return their input cost.

[Figure 5]

## 3.4 Estimates of Propensity Score Matching (PSM) analysis

Non-adapter and adapter socioeconomics characteristics descriptive statistics indicated the major difference in their access of institutional services, resources and incomes that illustrated the likelihood of affect of these features on their outcome of farm. Therefore, to overcome the biases of such external and internal factors the propensity score matching approach applied to estimation the causal influence of adaptation on outcome of crop. In the section of methodology illustrated as PSM initiates with propensity score estimation by application of regression analysis.

### 3.4.1 Propensity score estimation by application of probit regression

Probit regression estimates indicated as farmer's access of institutional services, income and farm size prominently affects their decisions to climate change adaptation as indicated in Table 4. In particularly, farmer's primary occupation, landholding, livestock and irrigation ownership sources indicated positive and significant whereas income of farm illustrated negative and significant association with adaptation decisions. Estimates of marginal effect additionally illustrated increase in animal one unit in livestock raises possibility to adapt climate change 2.9% and land size one acre increase possibility to adapt climate change 2.7%. Such of these results illustrated as farmers with higher herd size and farm land highly considered in adaptation to climate change as these results are consistent with the studies of Alauddin and Sarker, (2014), Abid et al., 2016), Zhai et al., (2018). Such measures makes feasible with more farm assets that capable them to application of different farm management strategies for climate change adaption. Availability of higher livestock highlights likelihood of plentiful availability of organic fertilizer that causes to facilitate farmers to application of fertilizer-induced adaptation approaches. Livestock also considered reserve capital of farmer in condition of emergency, mostly utilized as selling it for protect their livelihood from climate change severe affects (Ahmad et al., 2019; Sertse et al., 2021). Land ownership coefficient is negative and insignificant indicating as compared to owner, tenant's farmers higher motivated in application of climate change measures. Such scenario could be due to some significant factors such as land rent pressure, induces tenants to application of climate change measures for higher earning to fulfill the land rent additional cost.

[Table 4]

In farming practices irrigation access through canal and tubewell considered more essential factor regarding wheat cultivation as illustrated the more positive and significant association with farmer decisions of adaptations. Estimates of marginal effect indicated as wheat farmers with own tubewell irrigation access implement 19% more climate induced adaption measures rather than those farmers having no own irrigation access. In winter season shortage of irrigation water adversely effects wheat crop yield so adequate irrigation water access to wheat crop through tubewell considered main climate change adaption strategy for higher yield and coping severe effects of climate change as results are consistent with the research work of Alauddin and Sarker, (2014) and Ahmad et al., (2019). Adaptation decisions of farmers have considerably influenced by farmers off-farm and farm based income. In the scenario of adaptation decisions, off-farm income illustrated positive and significant whereas farm based income indicated negative and significant association. Farm based negative influence highlighted that farmers have lesser possibility of adaptation while increased farm based income. The reasons may be as farmers having higher farm assets and wealth less worried about climate dynamics regarding wheat yield losses and having no motivation to climate based adaptation strategies as findings are similar with the study of Zhai et al., (2018) and in contrast with the study of Joshi et al., (2017) and Ahmad et al., (2019).

Adaptation behaviour of farmer is prominently influenced by institutional support as estimates of the study illustrated positive and significant effect of credit access on farm based climate change adaptation measures. Marginal effect results indicated as farmers having access of credit having 25% higher possibility of using climate induced adaption measures rather than those farmers having no access of farming credit. The reason is that the financial support builds up confidence level of farmer such as in drought shocks and temperature shocks credit capable farmers to final major measure about farm based management strategies which causes to minimize climate change adverse effects regarding wheat crop. These results are similar with the studies of Alam et al., (2016), Ullah et al., (2018) and Ahmad and Afzal, (2020). Estimates indicated the positive and significant coefficient of advisory services illustrating as crucial role of advisory services in wheat farmers adaptation of climate change strategies. Marginal effect values elaborated as farmers having the access of advisory services 28% more probably to adapt climate change strategies in contrast to farmer have no access of advisory services. Agro-based advisory services lead and facilitates farmers to protect weather variation yield losses through late or early cultivation and climate smart practices as these conclusions are in line with the studies of Khan et al., (2019), Ahmad et al., (2019) and Mahmood et al., (2021). Climate based information with positive and significant coefficient indicated as farmer's familiarity about weather, increases farmers becomes more motivated to adaptation of climate based measures. Marginal effect estimates illustrated as wheat farmers those having access of climate change information from agricultural and metrological official's 35% higher likelihood to adopting climate based adaptation measures as these conclusions are consistent with the studies of Ahmad and Afzal, (2020) and Khan et al., (2021).

## 3.4.2 Adaptation causal effect on wheat crop yield and return

Propensity score was firstly estimated and then NNM matching technique was applied to estimate the casual influence of adaptation (treatment) on non-adapter (control) and adapter (treated) group. Table 5 indicated the influence of treatment on control and treated groups illustrating the values of variables outcome wheat crop yield and total return prior ATE and propensity score (ATT) post matching scenario. Farmers prior matching their internal and external factors known unmatched (observable covariates) also refers in population Average Treatment Effect (ATE) whereas Average treatment effect on treated denoted as (ATT). In regard the estimates of propensity score matching (PSM), Farmers measures of adaptation has largely raised wheat crop yield and total return as the values of ATE indicated an raise of 9.43 maund/per acre and 931.68kg per hectares in wheat yield from of adapter which caused wheat farmers rising total wheat crop return PKRs 18396 per acre and US$278.41 per hectares.

[Table 5]

In the same scenario ATT has also reported as treatment group also obtained raised wheat yield crop 3.14 maunds per acre and 310.23kg per acre whereas wheat crop total return PKRs 6927 per acre and US$82.75 per hectares as contrast to controlled groups. ATT lower value is because of potential bias reduction which affects impact of adaptation on wheat yield. ATT illustrated that adapter farmers regardless of their socioeconomic status mostly raised wheat yield and obtained higher total wheat crop return rather than non-adapter wheat farmers in the study area. Adaptations measures reduces the severe impacts of climate change also positive and significantly influences the wheat crop yield and total wheat crop return as empirically justified from these estimates in this study. These results are in line with the studies of Thaler et al., (2012), Huang et al., (2015), Ali and Erenstein, (2017), Khanal et al., (2018) and Ahmad et al., (2020). In such scenario in the region or country where millions of households population depends on wheat crop for nutrition need and livelihood adaptation measures needs to higher priority for avoiding wheat yield losses and coping adverse impacts of climate change.

### 3.4.3 Propensity score evaluation

In the scenario of estimating casual influence of treatment on variables outcomes it is prerequisite to evaluate results adequacy. In such method, firstly values of p>chi$^2$, LR chi$^2$ and Pseudo-R$^2$ were estimated after and before matching the p-score p(X). In Table 6, statistics regarding test illustrated that values of p>chi$^2$, LR chi$^2$ and Pseudo-R$^2$ significantly decreased afterward matching propensity score of respondents. Subsequently, median and mean biases also estimated to evaluate the results adequacy in term of reducing biases of selection.

[Table 6]

Estimates illustrated median biases reduced 59 to 7% and mean biases reduced from 64 to 10% elaborating significant reduced bias of external and internal covariates. On the basis of such indicators it can be summarized as estimates of propensity score matching have precisely evaluated treatment (adaptation) impact on farmers outcomes (wheat yield) despite of inherited variations in socioeconomic characteristics of farmers (Rubin, 2001; Ali and Abdulai, 2010; Ahmad et al., 2019). Biased reduction detailed description illustrated in Table 7 as given below.

[Table 7]

## 4. Conclusion And Suggestions

In Pakistan millions of households livelihood and nutrition based on wheat cultivation whereas in the current decade notable decline in wheat crop production estimated because of severe climate change-induced factors such as erratic rains, dynamic temperature and extreme natural events. In the region, wheat productivity can mitigated from climate-induce severe impacts by implementing on-farm autonomous adaptations (OFAA). This study attempted to investigate farmers OFAA strategies and evaluated their impact on wheat crop production and its returns by application of collect data from production based lower, medium and higher categorized six districts of Punjab, Pakistan. Changing seed varieties, farm resizing, irrigation application time variation, management of fertilizer, wheat cultivation dates changes and application of supplementary irrigation indicated significant farmers OFAA strategies as implemented by farmers in the study area. Non-adapter and adapter wheat farmers, wheat crop yield and total return was compared and estimates illustrated adapter farmers having higher wheat yield and total return because of application the climate-induced OFAA strategies. Propensity score matching (PSM) approach was also employed for statistical comparison of non-adapter and adapter related to observational base selection bias. Propensity score matching estimates indicated adapter farmers implementing climate change measures regardless of their socioeconomic variations still obtained higher wheat yield 3.14 maunds per acre and 310.23kg per hectares whereas wheat crop total return PKRs 6927 per acre and US$82.75 per hectares rather than non-adapter farmers. Farm feathers and socioeconomic characteristics significantly influence farmer's decisions of OFAA adaption strategies. Livestock procession, irrigation sources ownership, agriculture as primary occupation, farm size, farm advisory services and credit access illustrated positive and significant relationship with adaptation decisions of farmers.

On-farm autonomous adaptations, positive impact on farmers income and wheat yield has significant implications in reduction of Pakistan financial and nutritional poverty because majority poverty-deprived population inhabited in rural areas of country. In scenario of wheat crop vulnerability, applications of OFAA measures significantly raised wheat crop yield so in future possible losses due to climatic risks can overcome thorough implying OFAA strategies. In farm level, long term effects tackle through planned adaptation measures whereas farm level sudden responses can effectively meet and feasible through autonomous adaptation measures. More specifically in agro-based developing economies like Pakistan, autonomous adaptation has higher feasibility where limited interventions regarding policy level and institutions based acknowledged about planned adaptations. Furthermore, autonomous adaptations in limited efforts may develop resilience and adaptive capacity of marginalized and resource-poor farming groups against climate based hazards. Research findings may guide the policy makers, future researchers and climate governance practitioners to developing framework, adaptation policy and vulnerability modeling. These estimates are limited to Punjab province wheat crop similar regions and countries may also attain implications for evaluate farm level adaptation efficiency and formulating to managing risk based policies. This study has some significant limitations such as in reducing climate change variability's and their impacts all indicated adaptation strategies are not such significant. These districts research findings cannot be generalized to other districts because of some regional, environmental and socioeconomic disparities.

# Declarations

Ethical Approval

Ethical approval taken from the COMSATS University Vehari campus, ethical approval committee

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Authors Contributions

DA analyzed data, methodology, results and discussion, conclusion and suggestions and manuscript write up whereas both DA and MA finalized and proof read the manuscript and both authors read and approved the final manuscript.

Funding

This study has no funding from any institution or any donor agency.

Competing Interests

The authors declare that they have no competing interest.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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# Tables

Table 1
Study area sampling framework

| Categorizes wheat production areas zone | Study districts | Study sub-districts | Selected respondents |
|---|---|---|---|
| Low wheat yield zone | Dera Ghazi Khan | Kot Chutta, Dera Ghazi Khan | 80 |
| (Lower than 600,000 tonnes) | Layyah | Karor Lal Esan, Layyah | 80 |
| Medium wheat yield zone | Muzaffargarh | Alipur, Kot Addu | 80 |
| (600,000 to 900,000 tonnes) | Vehari | Malsi, Vehari | 80 |
| High wheat yield zone | Rahim Yar Khan | Khanpur, Sadiqabad | 80 |
| (above 900,000tonnes) | Bahawalnagar | Haroonabad, Chishtian | 80 |
| Grand Total | | | 480 |

Table 2
Study variables description

| Variables outcome | Description of variables | | Types of variables |
|---|---|---|---|
| Wheat yield | Per acre maunds[1] | | Continuous |
| Total wheat return | Wheat crop total return in PKRs[2] (thousands) | | Continuous |
| Cost of inputs | Inputs total cost per acre PKRs[3] (thousands) | | Continuous |
| Explanatory variables | Description of variables | Types of variables | Expected sign of variables |
| Age of farmers | Age in years | Continuous variable | ± |
| Education of farmers | Schooling in years | Continuous variable | + |
| Size of households | Number of household head members | Continuous variable | ± |
| Occupation primary level | Farming =1 otherwise = 0 | Dummy variable | ± |
| Size of landholding | Acres in numbers | Continuous variable | + |
| Ownership of land | Farmer owner=1 otherwise =0 | Dummy variable | ± |
| Ownership of tubewell | Farmer own tubewell= 1 otherwise=0 | Dummy variable | + |
| Land canal irrigated | Percentage irrigated by canal water | Continuous variable | + |
| Holding livestock | Animals numbers | Continuous variable | + |
| Income of farm | PKRs in thousands | Continuous variable | + |
| Labor of farm | Number of labor at farm activity | Continuous variable | ± |
| Income at off-farm level | PKRs in thousands | Continuous variable | ± |
| Advisory at farm level | Advisory received by farmer =1 otherwise =0 | Dummy variable | + |
| Services of credit | Credit utilized by farmer =1 otherwise =0 | Dummy variable | ± |
| Information of climate | Climate information access by farmer =1 otherwise = 0 | Dummy variable | + |
| [1]Wheat measuring unit (1 maund =40 kg) | | | |
| [2]Pakistan’s land unit (1 hectare = 2.47 acre) | | | |
| [3]PKRs = when survey carried out in 2020, 1$= 166.23 PKRs | | | |

Table 3
Adapter and non-adapter farmers' comparison mean value

| Study variables | Adapter farmers (374) | | Non-adapter farmers (106) | | Difference (non-adapter-adapter) | Pooled sample (480) | |
|---|---|---|---|---|---|---|---|
| | Mean value | Standard deviation | Mean value | Standard deviation | | Mean value | Standard deviation |
| Wheat yield (maund[1] per acre) | 58.79 | 7.354 | 49.36 | 6.326 | -9.43 | 54.075 | 6.987 |
| Return of wheat per acre (PKRs) | 43.76 | 6.465 | 34.62 | 5.287 | -9.14 | 39.19 | 5.975 |
| Input const | 38.54 | 5.651 | 32.47 | 4.941 | -6.07 | 35.505 | 5.921 |
| Age of farmers | 45.27 | 10.67 | 50.91 | 11.99 | -1.76 | 48.09 | 12.04 |
| Education of farmers | 8.14 | 4.99 | 6.47 | 3.74 | -1.33 | 7.11 | 4.72 |
| Size of households | 8.02 | 5.23 | 6.84 | 4.58 | -0.78 | 7.43 | 4.87 |
| Occupation primary level | 0.889 | 0.361 | 0.613 | 0.489 | -0.276 | 0.751 | 0.386 |
| Size of landholding | 8.97 | 6.452 | 5.67 | 4.64 | -3.3 | 7.32 | 5.89 |
| Ownership of land | 0.968 | 0.296 | 0.843 | 0.387 | -0.125 | 0.9055 | 0.281 |
| Ownership of tubewell | 0.891 | 0.453 | 0.327 | 0.413 | -0.564 | 0.609 | 0.457 |
| Land canal irrigated | 18.76 | 14.764 | 8.654 | 11.342 | -10.106 | 13.707 | 11.541 |
| Holding livestock | 7.541 | 4.032 | 4.321 | 3.154 | -3.22 | 5.931 | 4.167 |
| Income of farm | 48.572 | 28.487 | 24.853 | 20.359 | -23.715 | 36.7125 | 25.431 |
| Labor of farm | 3.487 | 1.758 | 1.976 | 1.367 | -1.511 | 2.7315 | 1.876 |
| Income at off-farm level | 12.876 | 11.041 | 10.897 | 10.117 | -1.979 | 11.8865 | 10.754 |
| Advisory at farm level | 0.764 | 0.543 | 0.379 | 1.342 | -0.395 | 0.5715 | 0.4891 |
| Services of credit | 0.589 | 0.498 | 0.134 | 0.121 | -0.455 | 0.3615 | 0.431 |
| Information of climate | 0.843 | 0.573 | 0.349 | 0.231 | -0.494 | 0.596 | 0.376 |

[1]Maund is measurement unit (1maund=40kg)

Table 4
Estimates of Propensity Score Matching by application of Probit regression

| Independent variables | Coefficient of variables | Standard error | P>z | Marginal effect |
|---|---|---|---|---|
| Age of farmers | 0.014 | 0.21 | 0.617 | 0.0019 |
| Education of farmers | 0.023 | 0.047 | 0.769 | 0.0020 |
| Size of households | 0.196 | 0.112 | 0.178 | 0.0224 |
| Occupation primary level | 0.897 | 0.365 | 0.026 | 0.1267 |
| Size of landholding | 0.194 | 0.113 | 0.081 | 0.0275 |
| Ownership of land | -0.041 | 0.367 | 0.875 | -0.0039 |
| Ownership of tubewell | 1.342 | 0.263 | 0.001 | 0.1932 |
| Land canal irrigated | 0.037 | 0.017 | 0.006 | 0.0049 |
| Holding livestock | 0.197 | 0.084 | 0.028 | 0.0298 |
| Income of farm | -0.063 | 0.032 | 0.037 | -0.0091 |
| Labor of farm | -0.024 | 0.198 | 0.897 | -0.0026 |
| Income at off-farm level | 0.0386 | 0.028 | 0.048 | 0.0063 |
| Advisory at farm level | 1.698 | 0.494 | 0.002 | 0.2784 |
| Services of credit | 1.795 | 0.736 | 0.009 | 0.2478 |
| Information of climate | 0.243 | 0.271 | 0.452 | 0.0354 |
| Constant | -4.137 | 1.243 | 0.001 | |
| LR$\chi^2$ (16) = 234.721 | | Log likelihood = -79243 | | |
| Prob > $\chi^2$ = 0.000 | | Pseudo-$R^2$ = 0.421 | | |
| Observations numbers = 480 | | | | |

Table 5
Adaptation casual effect on wheat crop yield and return

| Outcome variable | Type of sample | Treated (adapter) | Controls (non-adapter) | Difference |
|---|---|---|---|---|
| Wheat yield (maunds per acre) | Unmatched (Average Treatment Effect in population (ATE)) | 58.79 | 49.36 | 9.43(931.684 kg per hectares) |
| | Matched (Average Treatment effect in Treated (ATT) | 54.38 | 51.24 | 3.14(310.232 kg per hectares) |
| Wheat crop total returns (thousands PKRs per acre) | Unmatched (Average Treatment Effect in population (ATE)) | 114.64 | 96.252 | 18.39(US$278.41 per hectares) |
| | Matched (Average Treatment effect in Treated (ATT) | 106.841 | 99.918 | 6.92(US$82.75 per hectares) |

Table 6
Balancing covariates before and after matching

| Indicators | Before matching | After matching |
|---|---|---|
| Pseudo $R^2$ | 0.3987 | 0.089 |
| p>chi2 | 0.000 | 0.573 |
| LR chi2 | 234.16 | 13.47 |
| Median Bias | 59.1 | 7.8 |
| Mean Bias | 64.3 | 10.2 |
| R | 4.76[a] | 0.98 |
| B | 235.1[a] | 67.3[a] |
| Percentage of Var | 64 | 21 |
| [a]if R is outside the (0.5; 2), B>25percent | | |

Table 7
Propensity scores evaluation

| Explanatory variables | Means | | | | t-tests | | V(T)/V(C) |
|---|---|---|---|---|---|---|---|
| | Treated | Control | Percentage bias | Percentage bias reduction | t | p>\|t\| | |
| Age of farmers | 51.674 | 50.247 | 7.1 | 19.3 | 0.41 | (0.697) | 1.56 |
| Education of farmers | 6.238 | 6.732 | -1.43 | 89.53 | -0.07 | (0.876) | 1.59 |
| Size of households | 7.248 | 7.021 | 2.38 | 91.67 | 0.11 | (0.843) | 1.87[a] |
| Occupation primary level | 0.84 | 0.79 | 6.8 | 89.34 | 0.39 | (0.731) | 0.69 |
| Size of landholding | 6.054 | 5.642 | 3.9 | 88.97 | 0.41 | (0.691) | — |
| Ownership of land | 0.874 | 0.7931 | 19.75 | 20.86 | 0.96 | (0.357) | — |
| Ownership of tubewell | 0.685 | 0.397 | 36.8 | 76.64 | 1.76 | 1.29 | — |
| Land canal irrigated | 10.451 | 11.876 | -7.8 | 86.23 | -0.48 | 0.621 | — |
| Holding livestock | 5.753 | 4.234 | 18.76 | 67.21 | 1.37 | 0.148 | 1.36 |
| Income of farm | 29,547 | 25,786 | 4.9 | 89.6 | 0.49 | 0.497 | 1.52 |
| Labor of farm | 3.46 | 2.79 | -11.83 | 74.65 | -0.59 | 0.47 | 0.89 |
| Income at off-farm level | 7.986 | 9.324 | -12.6 | 23.6 | -0.67 | 0.432 | 1.44 |
| Advisory at farm level | 0.0843 | 0.11542 | -8.7 | 91.54 | -0.59 | 0.493 | 0.46[a] |
| Services of credit | 0.0563 | 0.0834 | -18.6 | 79.6 | -1.98 | 0.038 | — |
| Information of climate | 0.4751 | 0.3426 | 7.9 | 81.43 | 1.49 | 0.176 | 1.22 |
| In scenario of variances ratios outside [0.58;1.73] | | | | | | | |

# Figures

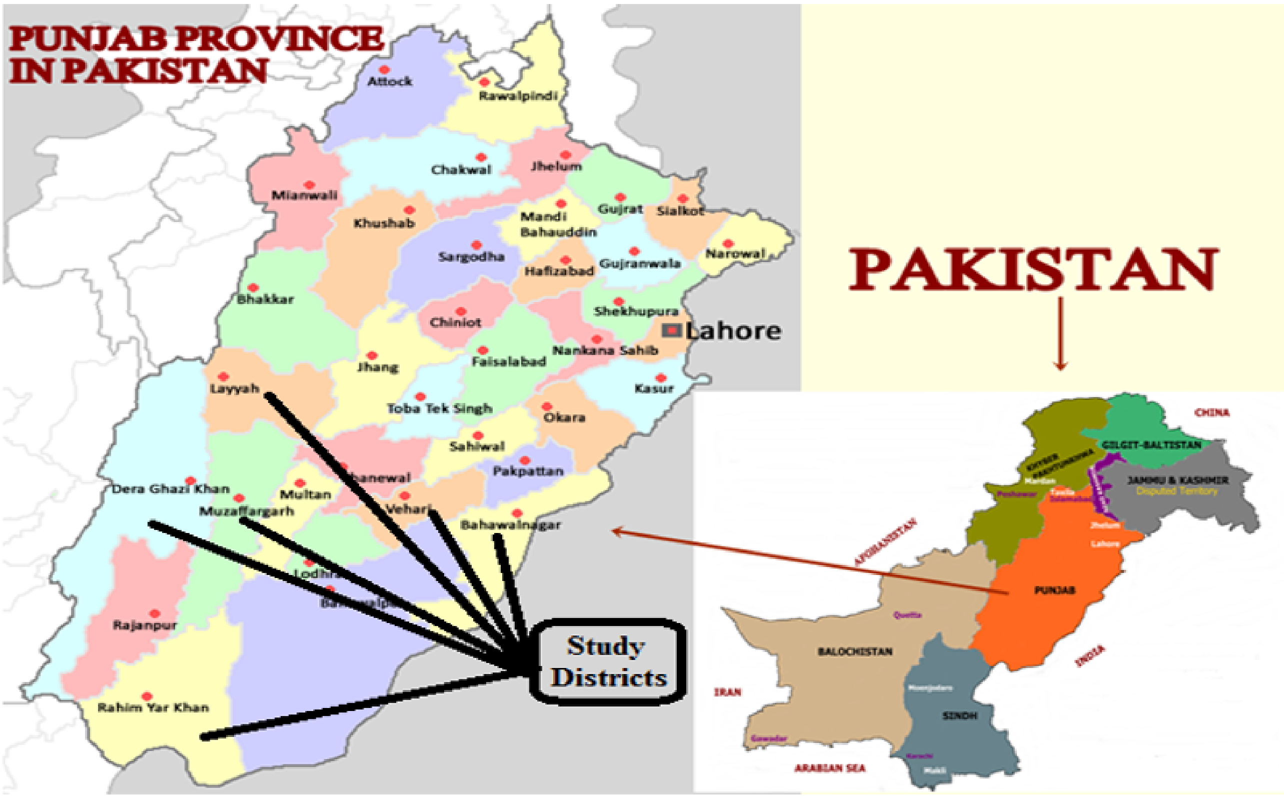


**Figure 1**

Map of study area districts of Punjab Pakistan

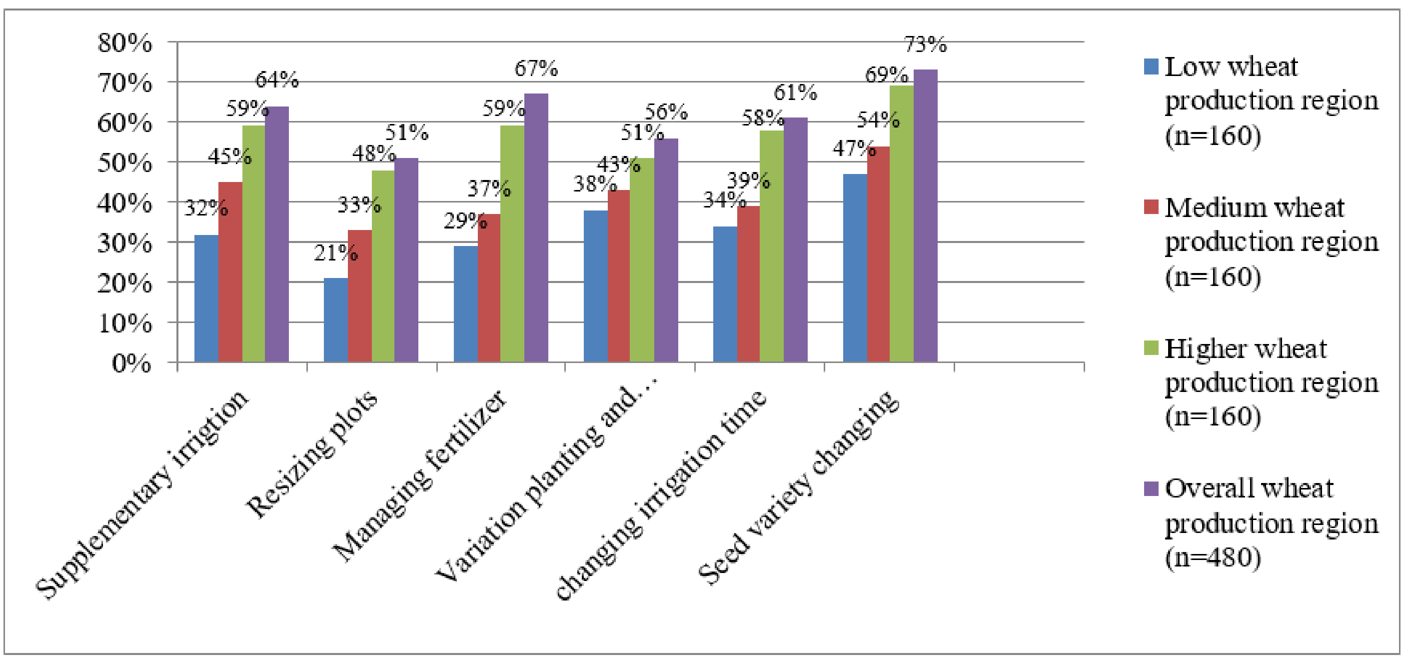


**Figure 2**

Climate change farmers adapted OFAA strategies

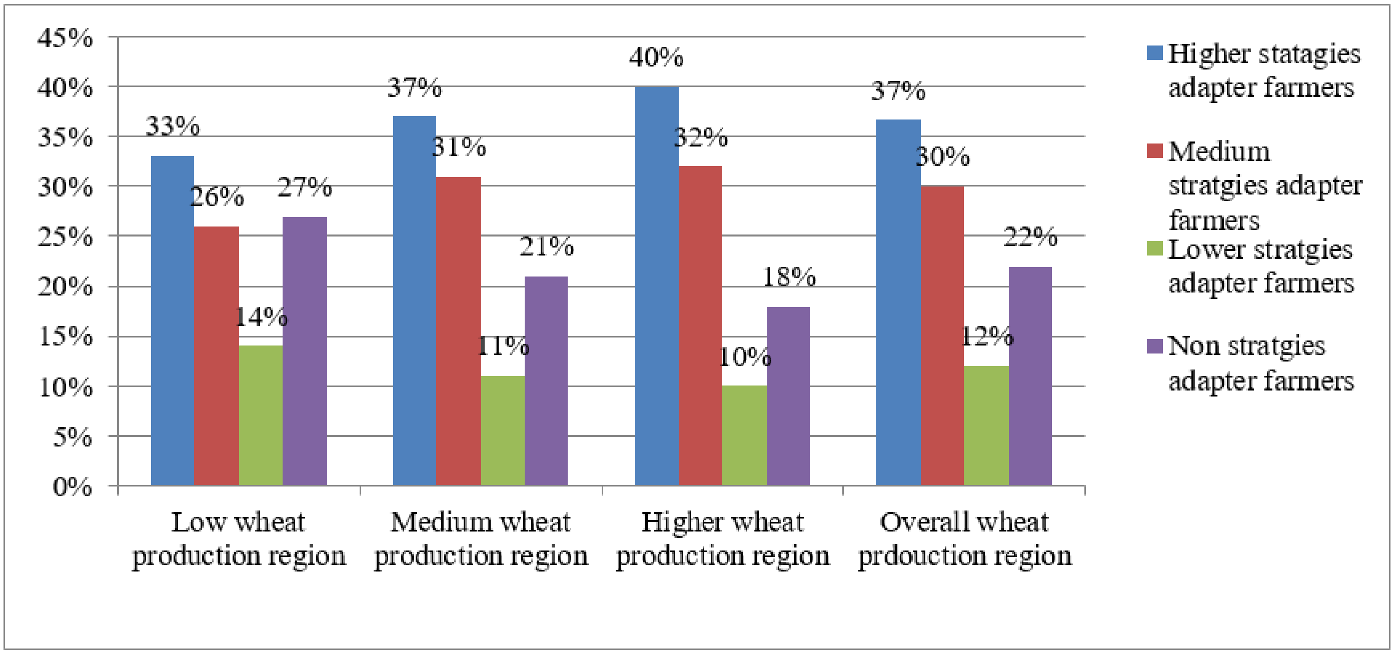


**Figure 3**

climate change adaptation classification in the region

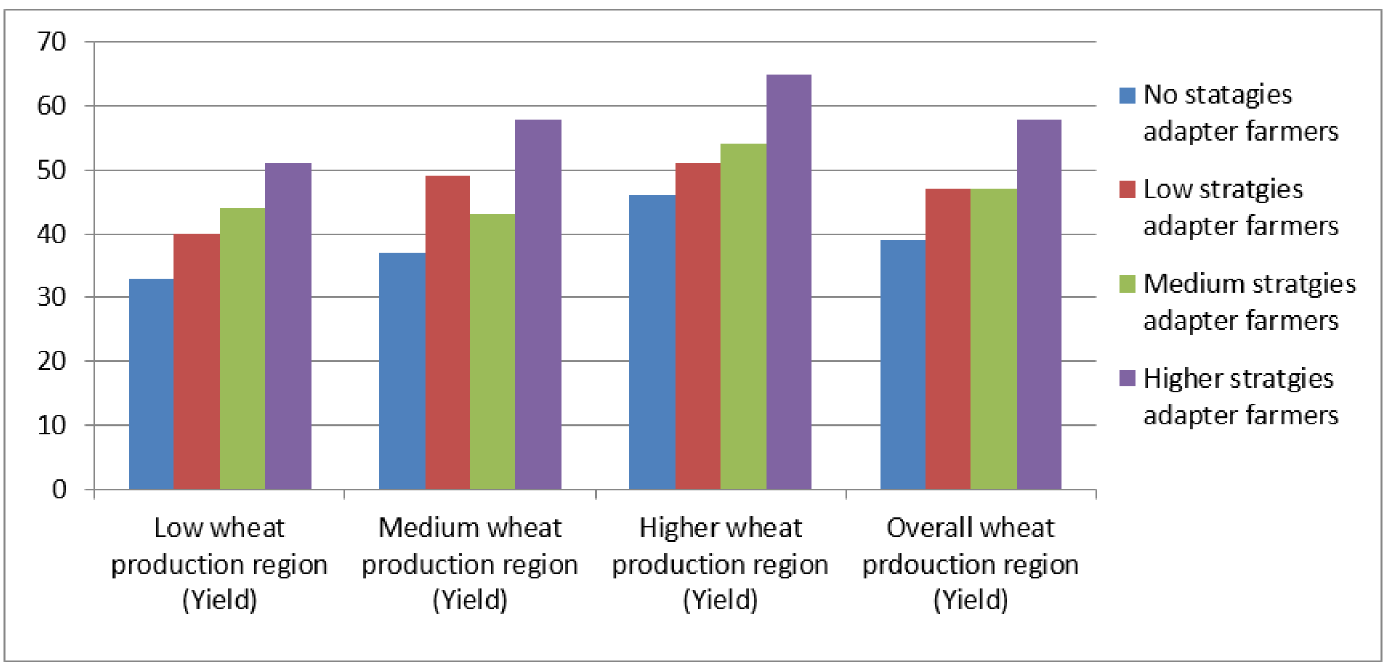


**Figure 4**

Climate change adaptation intensity its impact on wheat yield

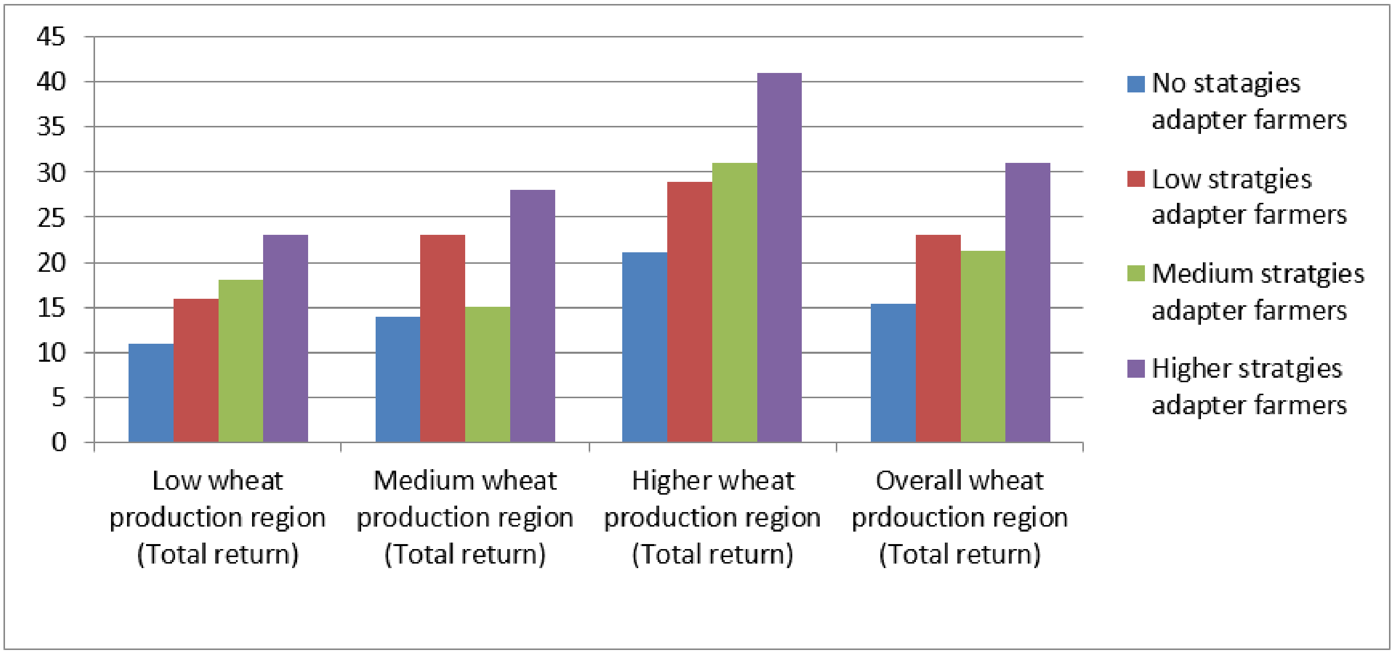


**Figure 5**

Climate change adaptation intensity its impact on wheat total wheat return in PKRs