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Impact of Smog on Wheat Productivity and Determinants of Smog Adaptation Options: A Case Study of Layyah and Lodhran

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Abstract

Smog is very harmful to agricultural productivity as it directly affects the growth and yield of crops. This study investigates the impact of smog on the wheat crop. For the present analysis, the study chose two agricultural districts (Layyah and Lodhran) of Pakistan. A survey was conducted from July to September 2019, by 400 farmers. Fully structured questionnaire is used for data collection while logit regression is used for empirical estimation. The results reveal that smog has a negative effect on wheat productivity as the size and weight of wheat grains decrease due to smog. The results also depict that the farmers' perception regarding adaptations options improves productivity. The results show that education, extension services, irrigation source, and credit services significantly impact adaptation options. The study suggests that government should take serious steps to get rid of smog as it adversely affects theproductivity of crops. For this purpose, strict enforcement of National Environment Quality Standards (NEQS) for the reduction of emission of smoke and other pollutants in the air by industry and other sectors can be useful. Additionally, government policy should target improving farmers' education (training and refresher courses), extension services, and credit facilities to increase farmers' adaptations.

Key Words*:* Climate Change, Smog, Adaptation, Perception, Determinants, Agricultural Productivity

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1. INTRODUCTION

Agriculture is an important sector in Pakistan's economy. The majority of the population, directly or indirectly, is dependent on this sector. It contributes about 24 percent of Gross Domestic Product (GDP), accounts for half of the employed labour force, and is the largest source of foreign exchange earnings. Pakistan faces serious challenges of land, water, and air pollutions (Padda and Asim, 2019). High percentage of pollution intensity directly affects economic growth, and poor people cannot protect themselves from the negative impacts of pollution. Several factors such as affect are affected by air pollution. Mainly carbon dioxide, nitrogen oxides, and other emission sources cause air pollution and are major causes of smog in winter in Pakistan. The smog is largely produced due to vehicles, industries, and the burning of different types of fuel. It has serious negative impacts on plants and crops. The most common pollutants are sulfur dioxide, black carbon, and particulate matter. NO_x is photochemical smog produced from burning materials, forest fires, industries, tobacco smoke, and all mobile vehicles, especially those operating with diesel engines. Nitrous Oxide contributes to the creation of smog and acid rain, as well as affecting ozone. Its peak time is early in the morning and evening, so workers cannot work in pre-dawn hours in the winter season. It may cause asthma, lung infection, eye irritation, cancer, and skin infection (Jin et el, 2014).

The crops and their yields are also being severely affected due to smog. Sulfur dioxide included in the fog destroys the roots of plants, and it influences both the quality and yield of agricultural products. Black carbon directly engages sunlight in reducing the amount of light available for crops to photosynthesize; thus, damaging yields (Burney and Ramanathan, 2014). Agriculture crops are affected due to smog pollution, and there is a significant reduction in productivity and quality of the product. The effect of smog on agriculture is very harmful because in the winter season, smog destroys the growth of wheat, cotton, soybean, in addition to other crops and plants. When smog affects the plants, farmers are forced to invest in expensive medicines for spraying purposes, resulting in reduced profits.

Numerous studies have been performed on the effects of climate change on crop productivity, and the results show that climate change decreases the productivity of crops (Stu et al., 2016; Devkota and Phuyal, 2016; Chhetri et al., 2012; Basnet, 2008) and determinants of climate change adaptation (Mendelsohn, 2012; Abid et al., 2015; Mabe et al., 2014; Hassan and Nhemachena, 2008; Maddison, 2007; Chhetri et al., 2012). Lobell and Asseng, (2017). Raja et el. (2018) explore the climate impact on plant health.

According to the study, in recent years, the Punjab region in Pakistan has been hit by smog during the winter months, which paralyzed urban life.

Smog is a long-standing problem in Pakistan, and in winter months of October till February, contaminates in the air in Punjab province shoot up, especially due to the burning of post-harvest rice stalks. Winter crops in Pakistan are also suffering at the hands of the deadly smog. While the field workers are unable to work in the fields as before, te crops and their yields are also being affected due to this variant of air pollution. A significant decline in the quality of agricultural produce has also been predicted. Standing crops are also poorly affected by foggy conditions. Wheat, a major crop of the winter season and a food staplein Pakistan, is also severely affected by it. Wheat production remained almost stagnant in the last decade as its production fluctuated between 23295 to 24946 thousand metric tons from 2007 to 2020. Overall yield loss is estimated between 10% to 30% due to smog. Ahamd (2015) assesses air pollution and its impact on crops in developing countries. This study shows the significant negative result of air pollution and nitrogen dioxide on crops in developing countries. Sun at el., (2018) examines air pollution, food production, and security. Air pollution has a negative result on food security since it affects plant expansion and is also dangerous for agro products or plants. Hence, air pollution significantly reduces vegetable prices and effects on consumer actions in the short run.

In developing countries such as Pakistan, limited literature is available on the smog effect on wheat crops. Therefore, the present study aims to estimate the smog effect on wheat crop in Layyah and Lodhran districts of southern Punjab. The wheat crop is selected for the study as it is the major crop of the season and is the staple food of Pakistan. The reduction in its production can create serious issues of food security. Despite interest in climate change adaptations at the local and regional levels, little literature is available on determinants and perceptions that affect the adoption of climate change adaptation options for wheat production. Therefore, this study aims to fulfill the said research gap. The present study decided to take two agriculture-based districts, Layyah and Lodhran, where smog destroys crops. Despite a variety of research about the environment, only few papers describe Pakistan’s case, especially in view of crop cultivators in rural areas. The Layyah and Lodhran districts are located in southern Punjab and have a major crop in the winter season. These districts are also seriously affected by smog. This study also estimates the determinants of adaptation services of climate change, such as smog. and focuses on seeking the impact of air pollution/smog on agriculture crops and the best adaptation options. It also aims to find out determinants of adoption options to avoid the negative effects of smog. Therefore, this study will be an important contribution to existing literature.

The paper is divided into five sections. Section one gives a brief introduction which includes the problem statement, significance, and objectives of the study. Section two discusses the review from previous studies and the literature gap. Section three discusses the theoretical framework of the model, variables, and methodology. Section four explains the results from our empirical analysis, and the last section discusses the conclusion and policy implications.

2. LITERATURE REVIEW

This section comprises relevant prior literature on the impact of climate change on crop productivity and various adaptation strategies towards climate change. Devkota et al. (2018) illustrated the case of Nepali farmers and their perceptions and barriers to climate change for rice crops. The empirical results reveal that climate change is significantly and negatively affecting rice crops. To cope with climate change, the farmers are practicing different adaptation strategies, including climate-smart rice varieties, use of chemical fertilizer, and change in nursery date. Furthermore, farmers also reported different barriers, including costly agricultural inputs, lack of access to funds, and non-availability and access to accurate information. On the same lines, Naqvi et al. (2020) revealed the barriers to adaptation to climate change in the four districts of Punjab. The essential factors to adaptation include age, education, land size, household size, and prices of agriculture inputs. In addition, poverty, and lack of access to funding opportunities are some of the hurdles to adaptation in the selected area.

Begho (2021) has explained that farmers’ risk attitudes play an important role in determining their adaptation perceptions. Most of the time, farmers are risk-averse and are afraid to use new technologies; this attitude has proved to be a great constraint to use new and latest technologies and seed varieties. Therefore, they cannot adapt to the changing nature of climate change and ultimately suffer from crop losses. In a similar study for Nepal, Khanal and Wilson (2019) elucidated the farmer’s perceptions towards climate change. According to the empirical findings, credit access, information about the variations in the climatic conditions, and farmers’ beliefs are the main influential factors towards climate adaptation.

Moreover, farmers' age and education are the two most essential variables paving the way towards climatic adaptations. For China, Zhang et al. (2020) explored different variables associated with adaptation towards climatic events. The study illustrates different obstacles towards climatic adaptation strategies, i.e., gender, age, education, and access to essential funds to buy agriculture inputs.

In another interesting study, Akugre et al. (2021) have illustrated various adaptation strategies Ghanaian farmers use. It includes plant or crop rotations and the use of new and improved varieties of seeds. In addition, the regression results revealed that tenure of occupancy and farm size are the most engaging factors in this regard. In another recent study, Atube et al. (2021) captured the farmers' adaptation practices towards Uganda's extreme climate events. According to the empirical estimates of logistic regression, the head of the household's gender and access to credit are a few important variables connected with overall adaptation. Nonetheless, access to credit and extension are two additional variables that are interconnected with climatic adaptation. The selected respondent farmer's gender and farm income are the two most important factors for better adaptation practices. In addition, access to road transport is also an essential variable for adaptation. In the same manner, farmers prefer to use new and improved varieties of seeds.

Bate et al. (2019) also illustrated the adaptation practices among farmers' communities in rural areas of Cameroon. According to the empirical estimations, farmers' connection or networking with other farmers is one of the strongest factors for adaptations. Moreover, non-farm income and means to buy improved seeds are also two important sources of adaptation among farmers. In Pakistan, Amir et al. (2020) took the case study of district Chakwal and illustrated different adaptation practices prevailing among farmers in the selected area. The most prominent strategy among all is to alter the crop plantation dates.

Further, years of schooling, farm size, household income, information, and access to necessary funds to improved seeds and other related inputs are few among many other determinants of adaptations. In another study based on cotton crops in Punjab, Pakistan, Ahmad et al. (2020) highlighted that due to different financial and non-financial constaints, farmers in the selected areas cannot adapt to climatic events. For example, due to financial constraints, poor farmers cannot afford high-quality seeds.

Based on the prior discussion, we can draw a few significant inferences. Climate change is exerting a significant and negative influence on crops productivity across the globe. Pakistan is a developing economy that is majorly dependent on the agriculture sector. In recent years, Pakistan has suffered from different climate change events, heat waves, lack of or excessive rains, and smog. Therefore, researchers must focus on such factors and find a suitable and affordable adaptation option for farmers. The present study is a valuable attempt in this regard. It will take the case of two agricultural districts, Layyah and Lodhran, and explore different options about adaptation towards smog.

3. DATA AND METHODOLOGY

This section comprises of the research design. We will explain selected methods and the reasons for that selection besides outlining the instruments, variables, and analytical methods used in the study. As mentioned previously, the study aims to assess the impact of smog on agricultural productivity in Layyah and Lodhran; additionally, we intend to estimate different adaptation options, which farmers adapt, to cope up with climatic events i.e., smog, in production. The study also elaborates the determinants of the choice of adaptation of a certain method to cope up with the harmful impacts of smog in Layyah and Lodhran. To accomplish the purpose, we have conducted a survey through structured questionairres. The present study is a cross-sectional analysis, and the research design is descriptive and analytical. The overall design of the study is presented below.

Research Design

Broadly, there are four types of research approaches: exploration, description, casual/functional explanation, and understanding (Baxter & Babbie, 2004; Mudombi, 2014 and Bryman, 2015). However, the present analysis is an exploratory analysis. An exploratory method is suitable when the researcher examines a new interest or when the subject itself is relatively new (Babbie, 2016). This study analyses the impact of smog on wheat production and different adaptation options, a relatively new field of inquiry in the case of Pakistan.

Study Area and Population

This study selected two districts of southern Punjab, Layyah, and Lodhran, where smog has severe effects on wheat. District Layyah consists of 6291 square kilometers and is divided into three Tehsils (Chaubara, Layyah, and Karor Lal Esan). Main crops cultivated in Layyah are sugarcane, wheat, cotton, gram, and guar seed. According to the census, 2017 total population of District Layyah is 1.82 million. There are 48 union councils (UCs), 24 UCs of Layyah, 17 UCs of Karor and 7 UCs of Tehsil Chaubara. District Lodhran covers an area of 2778 sq. km. The estimated current population is 1.571 million. *Lodhran consists of 3 Tehsils and 73 union councils, 11 of which are urban and 62 are rural. Lodhran produces 20% cotton of the country and 4% of the world, and major crops are wheat and cotton (*District Government Lodhran).

Sampling Methods

There are many farm households within the cluster. However, all the farmers in the villages face similar socio-economic, environmental, and climate conditions in their farming activities. They constitute a mostly homogeneous group, which validates a small sample size that can represent the entire population (Gilbert, 2008 and Blaikie, 2010). Therefore, a combination of multi-stage sampling and simple random sampling was used to select the villages and households where a questionnaire survey was carried out.

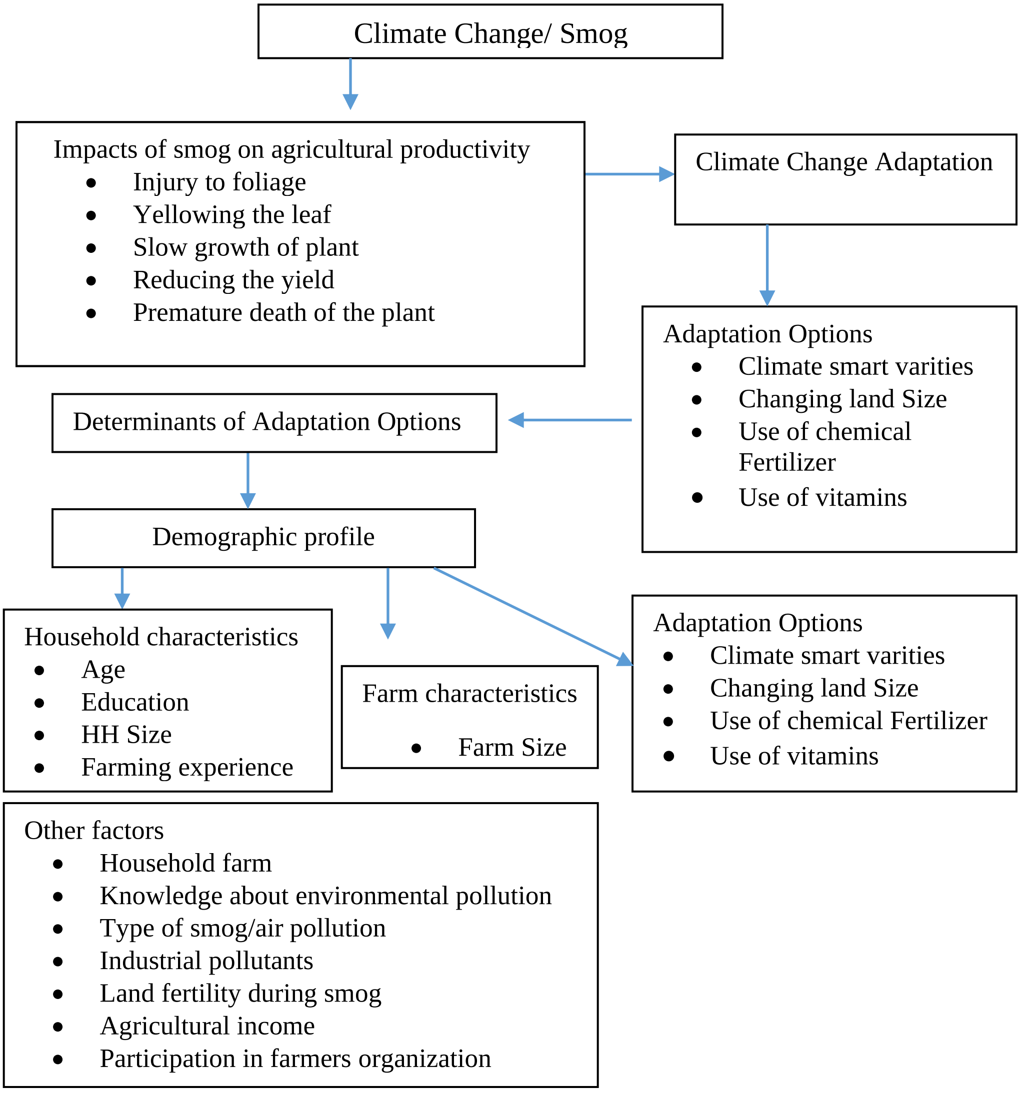
Only 2 districts have been selected as the study area. The authors have collected primary data without any financial support; hence, this study is limited to only two districts. Moreover, the two districts have similar geographical characteristics. Appropriate sample size depends on the original research questions and the design selected (Black, 1999 and Mumbai, 2014). Perry (1998) clarified that in qualitative research best sample size must be at least 350 for a structured interview. Following the literature, our study selected 400 farming households.

Methods of Study

Conceptual Framework

In the existing literature, we have found various options to cope up with the harmful impacts of climate change. However, the present study assumes that famers do not behave irrationally, when they have to make a choice regarding the best available adaptaion options in the market (Mendelsohn, 2012). The farmers try to choose these options based on their perception and also that particular option must give them the maximum benefit against the detrimental impacts of climate change (Maddison, 2007 and Deressa et al., 2011). Moreover, the farmers conducta cost benefit analysis of different adaptation options and opt for the one with the lowest costs and the maximum benefits (Pant, 2011). The benefits of these adaptaion options include an increase in crop yield and incomes of the farmers. Nonetheless, the prior literature cited that in most cases, the rich farmers have more, and better adaptation options as compared to their poor counterparts. (Pender, 2007 and Mendelsohn, 2012). The detailed conceptual framework is given below in Figure 1.

Figure 1: Conceptual Framework of the impact of smog on agricultural productivity and adaptation options



Analytical Framework

Descriptive Statistics

Descriptive statistics are used to describe the sample's characteristics, check the variable for assumption violation, and address the specific research question (Mudombi, 2014). The aim of undertaking descriptive statistics was to establish patterns and relationships, and to describe variables (Mudumbi, 2014). The patterns and structures in the data are discovered through the distribution of single variables and by relationships between variables (Adèr & Mellenbergh, 1999 and Mumbai, 2014). The descriptive analysis provides summaries to meet the research objectives and show the data's general picture (Coe, Stern, Allan & Beniest, 2002 and Mumbai, 2014).

Econometric Models

I. Impact of Smog on Agricultural Product

The first objective is related to observe the impact of smog on agriculture productivity. The dependent variable is a productivity of wheat per acre, which explains whether there is a decrease in wheat productivity due to smog in the selected area. The independent variables related to the household include the characteristics of the household, farm, and institutional factors. Table 1 explains the description and expected signs of variables.

$$Y_i = \beta_0 + \beta_i X_i + u_i$$

The independent variables have three categories: household, farm, and institutional factors. Some other factors, i.e., age, education, household sizes, and experience of forming, are included in households and impact crop productivity differently. Likewise, the farm size (large scale or small-scale) is considered as a farm characteristic. Similarly, access to information via extension services, credit access, and off-farm employment represent institutional factors.

II. Determinants of Adaptation Options

This study also aims to dig out the determinants of adaptation options to climate change. For this purpose, five models are estimated. The first model addresses the determinants of all types of adaptation options. The dependent variable includes all those farmers who adopt any adaptation option, the second model considers the determinants of climate-smart varieties. We consider all those farmers as dependent variables who use climate-smart varieties as adaptation option, in the third model we estimated determinants of changing land size. In contrast, the fourth and the fifth models consider the determinants of use of chemical fertilizer and use of vitamins respectively. The dependent variables in the third, fourth and fifth models are all farmers who use changing land size, chemical fertilizer, and vitamins, respectively.

$$AO_i = \alpha_0 + \alpha_1 Age_i + \alpha_2 Education_i + \alpha_3 HHsize_i + \alpha_4 Offfarmactivities + \alpha_5 Landsize_i + \alpha_6 Areaundercultivation_i + \alpha_7 Irrigationfacilities_i + \alpha_8 Farm\exp erience_i + \alpha_9 Extensionservices_i + \alpha_{10} Creditfacilities_i + \varepsilon_i$$

In the above equation, AO stands for adaptation options.

Table 1. Variables And their Expected Signs

Variables	Description	Value	Expected sign
Productivity Household characteristics			
Age	Age of farm household head	Years	±
Edu	Years of schooling	Years	+
HH size	Family members at a household	Number	±
Exp	Total farm experience	Years	+
Farm characteristics			
Fsize	Size of land of a farmer in acres	Ss	+
Institutional factor			
Extension	Whether household has access to extension service	1=yes , 0=no	+
Credit	Whether household has access to credit from any source	1=yes , 0=no	+
Climate information whether the household receives necessary information from any source		1=yes , 0=no	+
Off-farm activities income from off-farm activities		Quantity	±
Other factors: Impact of smog on agricultural productivity			

Household farm	Household farm in Layyah & Lodhran	1=yes, 0=no	±
Knowledge about environmental pollution		1=yes, 0=no	+
Type of smog/air pollution	Whether industrial pollutant is temporary or permanent	1= temporary 0= permanent	+
Industrial pollutants	Whether in industrial pollutants are dangerous for crops	1=yes, 0=no	+
Land fertility during smog		1= temporary 0= permanent	±
Other factors: Determinants of Adopting Adaptation Options			
Household farm	Household farm in Layyah & Lodhran	1=yes, 0=no	±
Agri income	Income received from agricultural activities	In rupees	+
Position of authority	If one has any form of authority	1=yes, 0=no	+
Participation in farmers organization	if any member of the households takes part in any farmer's orgnization	1=yes, 0=no	+
Participation in developmental organization	if any member of the household has participation in any developmental organization	1=yes, 0=no	+
Access to farming environmental magazines	Whether farm household has access to the farming environmental magazines	1=yes, 0=no	+
Ever talked about climate change	Farmers talked about climate change or not	1=yes, 0=no	+

Description of the Variables

Age

The impact of age on the adaptation is unpredictable because older farmers are usually risk-averse and do not easily accept new technology, whereas young farmers have risk tolerance. However, older farmers are more experienced and can easily understand about losses and benefits of different adaptation strategies (Naqvi et al., 2020).

Education

Education level is important for making decisions related to innovation. It is expected that households with higher education will have more ability to get more information related to new technologies and information about adaptation adoptions (Padda and Asim, 2019 and Naqvi et al., 2020)).

Household Size

We used the household size for the availability of persons who can work on farms. HH size is expected to positively relate to the adaptation because it decreases labour cost (Devkota et al., 2018 and Naqvi et al., 2020).

Farming Experience

The farm experience is expected to have a positive and significant impact of adopting new technologies because of better information of climate change conditions (Devkota et al., 2018 and Hameed, Padda and Salam, 2014).

Farm Size

Large farms have more probability of adopting different adaptations as compared to smaller farms because of the fixed cost involved in innovations (Devkota et al., (2018 and Naqvi et al., 2020).

Extension

A positive relationship exists between extension services and adapting because the provision of new information to the farmers increases their technical skills (Hameed, Padda and Salam, 2014).

Credit

Different adaptation options require a large investment; hence, an easy access to credit is positively related to adaptation ((Amir et al., 2020, Padda and Asim, 2019).

Climate Information

Climate information is positively related to adopting the adaptation because if farmers have adequate knowledge about smog peak time, they can easily decide about adaptation (Devkota et al., 2018).

Off-farm Activities

Off-farm activities can have both negative and positive impacts on adaptation. If farmers have other income generation activities, then theycan invest more in adaptation. On the other hand, farmers with off-farm activities have less time and interest for adaptation (Amir et al., 2020).

Household Farm

If the farmer owned a farm, there are more chances of adopting new technology (Padda and Asim, 2019).

Industrial Pollutants

Industrial pollutants are positively related to adaptations because if industrial pollutants are dangerous, then the farmer must adopt new technology to increase the yield (Padda and Asim, 2019).

Agricultural Income: If farmers realize that new technologies increase farm level income, they consider different adaptation options (Amir et al., 2020).

Position of Authority*:* If respondents can decide on farming, they can consider more adaptation (Devkota et al., 2018).

Participation in Farmer's Organization: For the awareness about smog and adaptation, the participation of a respondent in farmer's organization is important (Amir et al., 2020).

Access to Newspaper and Farming Environmental Magazines: Farmer's access to newspaper and environmental magazines has a positive impact on adaptation. Such access increases the farmers' current knowledge about smog and its effects (Padda and Asim, 2019).

Ever Talked about Climate Change: It refers to whether the farmer has talked or discussed smog with other people (Amir et al., (2020).

Data Collection, Entry, and Cleaning

The data were collected from a structured questionnaire and face-to-face interviews with the farmers and entered by researchers in an Excel sheet. The actual data entry was cross-checked for errors and completeness. After completing the entry process, the data was then cleaned and checked for outliers and no errors or outliers were found.

4. RESULTS AND ESTIMATIONS

Descriptive Statistics

Table 2 shows that the majority of the farmers were of working age. The minimum age among the respondent was 20 years, while the maximum age was 77 years. All respondents are male. Among the respondents, 89.75% were married, and 10.25% were unmarried. The average HH size of the respondents was 7.40, with a minimum of 1 and a maximum of 34 family members. We also included the education status of the household in our analysis so that we can observe the impact of different levels of education on crop cultivation. We divided education into seven categories: no education, primary, lower secondary, secondary, higher secondary, bachelour's, and masters. In total, 73% of respondents had a formal education, and 27% had no education.

Table 2. Descriptive Statistics

Explanatory Variables	Mean	SD	Minimum	Maximum
Age (years)	42.01	11.93	20	77
HH size (numbers)	7.40	4.32	1	34
Land size (acre)	13.87	28.59	1	450
Education (1 for yes 0 otherwise)	0.74	0.44	0	1
Vocational training (1 for yes 0 otherwise)	0.17	0.38	0	1
Tube well (1 for yes 0 otherwise)	0.20	0.40	0	1
Extension services (1 for yes 0 otherwise)	0.19	0.39	0	1
Credit facilities (1 for yes 0 otherwise)	0.82	0.38	0	1
Climate information (1 for yes 0 otherwise)	0.98	0.12	0	1

The education of the farmers is useful to get information from some sources on farming issues on varying weather and adaptation policy. In total, 377 respondents, 94.25% household heads were farmers and 23 respondents 5.75% have some other sources of income. Among the rest, 17% of respondents received vocational training and 19% farmers used the extension services. Extension services are helping to improve the knowledge about the adaptation of climate change. Interestingly, 98% of farmers were aware of climate change.

Impact of Smog on Agricultural Productivity

The logistic regression model is used to analyze the impact of smog on wheat production in districts Layyah and Lodhran. Table 3 gives estimated results.

Table 3. Impact of Smog on Agricultural Productivity

Variables	Coef.	Std.Err	T	P>|t|
Education	0.605	1.002	0.60	0.546
HH size	0.011	0.095	0.12	0.902
Land size	0.814*	0.246	3.31	0.001
Area under crop cultivation	0.884*	0.249	3.55	0.000
Farm experience	0.087**	0.034	2.55	0.051
Extension services	2.916*	1.104	-2.64	0.009
Credit facilities	4.791*	1.097	4.36	0.000
Knowledge about smog/pollution	2.879*	.833	3.45	0.001
Industrial pollutants	-6.944*	1.035	-6.71	0.000
Land fertility during smog	-4.923*	.993	-4.96	0.000

Note: * shows the significance at 1 %. ** shows the significance at 5 %.

The results show that area under crop cultivation, extension services, credit facilities, and knowledge about smog/pollution are significant at 1 percent and positively related to wheat productivity. Farm experience is statistically significant at 5% percent and positively related to the productivity of wheat. Smog is the main factor that destroys the crops in Layyah and Lodhran. Smog, a type of air pollution, causes the numbers of pollutants to rapidly grow in the environment (Stu et al., 2016; Devkota and Phuyal, 2016; Chhetri et al., 2012; Basnet, 2008). Knowledge about smog is statistically significant at 5%. If farmers are aware of the adverse effects of smog, they use different adaptation options for better production. Knowledge about smog is positively related to production. Industrial pollutants and land fertility during smog are significant at 1%, which shows a high probability level, but both variables indicate negative signs, indicating that variables have a negative effect on agricultural productivity. These results are similar to the ones deduced by Wahid et al. (1995), that argue that rice production reduces due to air pollution.

Due to smog, size and weight of wheat is decreased and eventually production is reduced. The results of our estimation show that smog creates several problems for crops and also for farmers due to an increase in the cost of production and loss of productivity. Schiferl and Heald (2018) and Yang and Suh (2015) also found a negative effect of smog on crop production. An increase in industrial pollutants is the main reason for smog. Thus, industrial pollution has a negative effect on the productivity of wheat. Additionally, smog temporarily affects land fertility, that results in low productivity of crops. Thus, the present study highlights that industrial pollution is becoming a serious threat to the fertility of land or crops in Pakistan.

Farmer Perceptions about Adaptations Options

Farmers use some adaptation options to avoid smog effects on crops. The farmers have different perceptions related to the increase in productivity of wheat by adopting various adaptation options. According to results, 51% of farmers have the perception that 10 to 20% of the productivity of wheat crop improves if they use adaptation options, while 28% have a perception of increase by 21 to 30%. The detailed results are presented in the table given below.

Table 4. Farmer's Perception about Agricultural Productivity

Increase in Productivity	Frequency	Percentage
10 to 20%	205	51.25
21 to 30%	115	28.75
31 to 40%	45	11.25
41 to 50%	35	8.75
	400	100

Table 5. Percentage of Farmers and their Use of Different Adaptation Options

Different Adaptation Options	Option	Frequency	Percent
Adaptation option	1	297	74.25
Climate smart verities	1	136	34.00
Changing land Size	1	92	23.00
Use of chemical Fertilizer	1	296	74.00
Use of vitamins	1	281	70.25

Determinates of Adaptation Options

Adaptation options measure the crop farming practices reducing the impact of smog on agriculture productivity. Descriptive analysis shows that 74.25% of respondents use all adaptation options for the betterment of productivity. Four adaptation options are considered in this study. The first one is the use of smart climate varieties, used by 34% respondents. The second is changing land size, adopted by 23% of farmers. The third and the most often used option by the farmers is chemical fertilizer. As many as 74% farmers use such fertilizers on smoggy days to protect the crops. The fourth adaptation option exercised by the farmers is the use of vitamins which is the most expensive option; however, 70.25% of respondents use it.

Our second objective is related to find the determinants of adaptations options to avoid adverse effects of smog on the production of crops on smoggy days. In order to achieve the objective, we first discuss the main determinants of adaptations as compared to no adaption. Logistic regression is applied to find out the main determinates of climate-smart varieties. We used age, household size, education, land size, off-farm activities area under crop cultivation, irrigation facilities, farm experience, extension services, and credit facilities. In the results of the overall adaptation model presented in table 6, seven factors significantly affect the choice of adoption of farmers. Among these significant variables, the level of education is statistically significant at 5%, that highlights education's importance for adaptation (Maddison, 2007; Chhetri et al., 2012). We included the education status of the household in our analysis so that we can observe the impact of education on crop cultivation. As the level of education increases, farmers use more adaptations and often increase the probability of adopting new adaptations. The household (HH) size is statistically significant at a level of five percent. The coefficient value is 0.041, which shows that farmers use more adaptations options to improve wheat productivity with the increase of HH size. Land size is significant at a one percent level with a positive sign, indicating that the probability of adoption is higher for large farmers. The area under crop cultivation significantly increases. Availability of credit to farmers is also significant, that shows that easy access to credit is also an important factor for the adaptation. The irrigation facilities are also a positive sign indicating that the probability of adoption is more for farmers who have irrigation facilities as compared to those who do not access to the same facilities. Here, the extension service also has a positive sign and is statistically significant, that shows the importance of extension services for the guidance and education of the farmers. For the first model, our results are similar to Deressa et el (2008) and Devkota at el (2018).

Model 2 is estimated by considering small climate varieties as an adaptation option used by farmers. Wheat growing farmers use the climate-smart varieties for the improvement of productivity. In our analysis, we used ten variables, among which seven variables are significant. The variables of age, household size, education, off-farm activities, area under crop cultivation, farm experience, extension services, and credit facilities are notable at a five percent level of significance. Education is the one way to be aware of the uncertainty of climate impact. Farmers with more education have more probability of using smart varieties. Therefore, in our study, educational level helps to increase the adaptation of the farmers, and it might be supportive when searching for information from numerous sources on farming issues on changing climate and adaptation strategies. Farmers adopt smart varieties of seeds for increase in crop production. The change in the size of the area under specific crops is also an important adaptation strategy. Model 3 shows that education, land size, the area under crop cultivation, irrigation facilities, farm experience, extension services, and credit facilities significantly affect the decision to adopt the change in the size of the area under wheat crop.

Chemical fertilizers are substances containing chemical elements that improve the growth of wheat. Chemical fertilizers are necessary for agricultural crops, especially in the smog period (Mendelsohn, 2012; Abid et al., 2015; Mabe et al., 2014; Hassan and Nhemachena, 2008). Chemical fertilizer is normally used for the production of crops, but in smog days, farmers use the expensive and extra amount of fertilizers to increase productivity and to improve the fertility of the land to avoid the negative effects of smog. Chemical Fertilizer use is very expensive and can harm the environment if it is not used properly. Model 4 depicts that education of the farmer, size of the land, the area under wheat cultivation, irrigation facilities, and availability of credit have a significant role in the adoption of the use of fertilizer as an adaptation option.

The last adaptation option that farmers of Layyah and Lodhran usually adopt is vitamin use. Vitamins improve the productivity level and protect the crops in smog days by increasing crop size and improving land fertility. Vitamins are responsible for assisting with the growth of crops. In the smog period, certain nutrients are needed in large quantities such as, potassium, phosphorus, nitrogen, calcium, sulfur, and magnesium. The said mnutrients are responsible for crops' growth and water retention. Nitrogen and calcium are essential for crops in smoggy days as they increase growth and development of crops. The results of model 5 show that education, land size, and area under crop cultivation are statistically and positively related to the use of vitamins that show that use of vitamins increases in smog days. It displays that due to an increase in credit access, there is a probability of increasing the use of vitamins, whereas the farmers can get the latest information from extension services and can use more vitamins.

Table 6. Determinates of Adopting Adaptations Option

	Model 1		Model 2		Model 3		Model 4		Model 5	
Variable	Overall adaptation		Climate smart verities		Changing land size		Use of chemical fertilizer		Use of vitamins	
	Coeff	Prob	Coeff	Prob	Coeff	Prob	Coeff	Prob	Coeff	Prob
Age	-.001	0.968	.054*	0.015	.021	0.306	-.005	0.813	-.0103	0.576
Education	.67**	0.022	.16**	0.026	.784*	0.016	.649**	0.026	.436*	0.008
HH size	.04**	0.042	.117*	0.000	.025	0.440	.038	0.221	.0309	0.285
Off farm activities	-.052	0.582	-.700	0.080	.112	0.312	.073	0.454	.099	0.254
Land size	.057*	0.002	-.014	0.843	.291*	0.000	.300*	0.002	.230*	0.006
Area under crop cultivation	.318*	0.004	.017*	0.016	.309*	0.000	.571**	0.051	.235*	0.005
Irrigation facilities	.848*	0.003	.5623	0.091	.592	0.091	.870*	0.003	.15**	0.041
Farm experience	-.016	0.147	.054*	0.012	-.053*	0.009	-.012	0.512	-.004	0.821
Extension services	.36**	0.037	1.99*	0.000	.495**	0.049	.388	0.218	.256	0.032
Credit facilities	.602*	0.017	1.74*	0.000	1.10*	0.000	.305*	0.002	.39**	0.031

5. CONCLUSION AND IMPLICATIONS

Smog is very harmful to agricultural productivity as it directly affects the growth and yield of crops. Pollution airborne affects economic growth and worsens poverty and variation in both urban and rural areas. Smog is very harmful to agricultural productivity; its direct impact on crops is in the reduction of growth and economic yield. The present study firstly finds the impact of smog on wheat productivity. Second, it finds out which adaptation practices are best among different adaptation options, i.e., the determinants of adoptions.

The logistic regression is used to find out the impact of smog on agricultural yield. Due to smog, productivity, and growth of wheat have been adversely affected as the size, and weight of wheat grains have decreased. The evidence shows that smog has created many problems for crops and farmers due to the increase in the cost of production and loss of productivity. It also has a temporary effect on the fertility of land. The study highlights that industrial pollution, the main cause of air pollution, is becoming a serious threat to the fertility of land or crops in Pakistan. The results depict those areas under crop cultivation, credit facilities, and extension services are significantly and positively related to wheat productivity. Farm experience is statistically significant and positively related to the productivity of wheat. Knowledge about smog is also positively related to production. Industrial pollutants and land fertility during smog are significant, showing a high probability level, but both variables have negative signs showing a negative effect on agricultural productivity.

Four adaptation options are considered to determine the determinates of adoptions, i.e., climate smart verities, changing size, use of chemical fertilizer, and use of vitamins. The results show that education, extension services, irrigation source, and credit services are positively and significantly related to adaptation options.

The present study's findings suggest that the government should take serious steps to eliminate smog as it adversely affects wheat productivity. For this purpose,strict enforcement of National Environment Quality Standards (NEQS) is needed by industry and other sectors for reduction in emission of smoke and other air pollutants. Subsidies should be provided to farmers to cope with the smog problem as there is an increase in the cost of production of wheat due to smog. Government policy should target improving farmers' education (training and refresher courses), extension services, and credit facilities to increase farmers' adaptations. Especially through education, farmers can learn about better adaptation options and climate uncertainty. The study has limited scope and may not be generalized for the whole of Pakistan or even Punjab as it is based on only two districts of southern Punjab. Future research may be done with more data based on all smog-affected areas of Pakistan.

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