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An Empirical Assessment of the Interactive Impacts of Irrigation and Climate on Farm Productivity in Samarkand region, Uzbekistan

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ABSTRACT

Analyzing climate change's consequences is more complex for irrigated agriculture compared to rainfed. There are still limited researches that has considered the interactive effects of irrigation and climate variables regardless the fact that a broad range of climate studies was already involved in international literature. In this view, this study aimed at exploring the cross effects of irrigation with climate on farm output using *ex-post* assessment technique in Uzbekistan, where agriculture contributes for a large portion of the national GDP and irrigation water is becoming scarce. We applied a Stochastic Frontier Approach (SFA) with panel data from the central-eastern part of Uzbekistan for the period of 2013–2018, which includes a sample of 2,135 wheat and 1,141 cotton growers. The analysis revealed that climate factors have diverse influence by crop types across the region. Increased warming would be harmful for wheat farmers: a one-degree Celsius rise in average temperature between March and June could lead to up to 60% losses of total yields on wheat-growing farms, although precipitation has a positive significant effect. In contrast, increased temperatures are beneficial for cotton-growing farmers but excessive rainfall during the months of May–September could lead to 3% losses of total yields on cotton-growing farms. It's expected that both wheat and cotton growing farmers will suffer from temperature increases and excessive precipitation on their farms in the near future. More importantly, the interaction effects of irrigation and climate variables show that the cross effects of applied irrigation and mean temperature have highly significant positive impacts on the total yields of both wheat and cotton growing farmers in the study region. Thus, productivity in the region could be improved when enough water is available and more efficient irrigation techniques are used, otherwise declines in productivity could be witnessed.

1. Introduction (background of study)

Climate change is an important environmental issue that disrupts global agricultural production, mainly where agriculture is the main activity. The adverse consequences of environmental change on agriculture and the jobs of the worldwide rustic local area have been broadly concentrated on involving different methodologies across the globe. Be that as it may, there is impressive conflict regarding how severe the unfavorable impacts of environmental change will be in various regions of the planet. Evidence recommends that high-income areas in the temperate regions confront less adverse results and profit from climate crisis

(Ludwig et al., 2007). Conversely, there is a scientific understanding that non-industrialized and low-income nations with tropical and subtropical environments are more helpless against the adverse consequences of climate change (Singer, 2018). Indeed, climate changes will profoundly affect the usefulness and productivity of crops and lead to enormous differences in agricultural outcomes. Elliott et al., (2014) explored that climate-induced threats posed strict water shortages in irrigated regions of the globe and necessitated conversion of cropland from irrigated to rainfed with noticeable losses on food production. Regions with tropical and subtropical environments are more susceptible to the adverse consequences of climate change (Raza et al., 2019).

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To support the scientific evidence, there are online supplementary materials for the reviewed studies. Liu et al. (2004) emphasized the impact of climatic events on net agricultural revenue by regressing farm institutional factors towards climate variables. The study explored a beneficial effect of higher temperatures and more precipitation on China's agriculture. In contrast, Wang et al. (2009) studied that changes in climate variables were moderately harmful at first. Still, the losses would worsen over time if the same agricultural inputs were used in China. Further researches have revealed that agriculture is more climate/water-sensitive in developing regions due to poor institutional and adaptive capacities. Ouedraogo et al. (2006) found negative impacts of temperature increases and positive impacts of rises in rainfall on the net revenue of farms in Burkina Faso. Gbetibouo & Hassan (2005) also applied Ricardian approaches to their climate analyses and found similar results to Behnin (2008), that is that temperature rises would positively affect net revenue, but the effect of rainfall reductions would be harmful in South Africa. Molua (2009) and Ngondjeb (2013) utilized econometric models to analyze the adverse consequences of climate-related extremes on net agricultural income in Cameroon. As per their results, temperature increase leads income reduction for both irrigated and rain-fed farmers.

Elsewhere in the world, Kumar (2014) also studied temperature and rainfall variations on total yields of agricultural crops using panel regression data from India. They found that the productivity of crops is sensitive to climate and negatively influenced by temperature increases and excessive rainfall. In accordance, Alboghdady & El-Hendawy (2016) also found the adverse effect of temperature and precipitation increases on net agricultural production in the case of the countries of Middle East and North African region. Ali et al. (2017) also explored the climate impacts of the total yields of major crops in Pakistan using the feasible generalized least square method. Their findings reveal that maximum temperatures negatively affect wheat production, whereas minimum temperatures have significant positive influences on crop growing. Rainfall, on the other hand, has been found to harm crop yields in Pakistan, except for wheat. Accordingly, the adverse effects of rises in temperature and rainfall on farm revenues during the dry season in Vietnam was also explored by Huong et al. (2019). Furthermore, net revenue is predicted to decline with or without adaptation models due to climate change consequences between 2050–2100 in Vietnam.

It's important to note that the farm location and irrigation are also major variables that have an influence on crop growing. In fact, Gupta et al. (2014) studied the effect of climate-induced hazards on India's major food crop (rice paddy productivity). Results of panel analysis show that rice paddy productivity is sensitive not only to climate variations, but also to fertilizer application and the share of irrigated area. Charles (2014) also investigated the effects of environmental shocks and the significance of water systems in the case of inundated and downpour-affected farming producers in Zimbabwe. Cross-sectional data at the family level was used, and the water system was incorporated as a dummy variable into the regression. Household level cross-sectional data was employed and irrigation was incorporated as a dummy variable into the regression. The findings show that agricultural production is significantly constrained by climate factors and that irrigation offers better adaption for farmers, especially against future climate shocks in dry zones. In line with this, Hossain et al. (2019) also found a beneficial effect of increased warming on the net agricultural incomes of farms with sufficient irrigation facilities, although agricultural production was found to be climate sensitive, especially to seasonal temperatures in Bangladesh. More interestingly, the impact of irrigation was stated either as the proportion of irrigated land in the whole structure or as farms having active access to irrigation sources (dummy) in the existing literature.

Nonetheless, there is still little known and a few studies that have applied *ex post* assessment methods to investigate the interaction impacts of applied irrigation amounts with climate factors (temperature and precipitation) on selected crops at farm level within the international literature. In order to fill this research gap, this study attempts to

investigate the cross impacts of applied irrigation amounts and observed climate variables, such as mean temperatures and accumulated mean precipitation amounts on farm productivity using an *ex-post* assessment method. *Ex post* evolution methods enable to provide practice-based results and to draw comprehensive understanding of actual challenges as well. To serve this objective we adopted stochastic frontier model (SFA) and both climate and panel data from wheat and cotton farmers in the central region of Uzbekistan. The estimations results will reveal that observed climate variables together with available irrigation influenced either positively or adversely to wheat and cotton yield. Furthermore, the empirical findings of this research work could have important implications for farmers in terms of fully understanding climate consequences and the importance of water for their performance, as well as increasing their resilience against future climate threats in the face of rising temperatures and existing water scarcity.

2. Climate change in Central Asia

Central Asian countries under agricultural transition are highly sensitive to climate shocks due to their heterogeneous geography and institutional changes following their independences (Lioubimtseva and Henebry, 2009). Since the 1950s, there has been intensive changes in climate with observed temperature increases that are greater than the global average with only modest changes in precipitation, although this has induced seasonal water shortages for agricultural purposes and also reduced crop yields in Central Asia (R. Gupta et al., 2009; Yin et al., 2016; Reyer et al., 2017). The relationship between wheat yield and drought was investigated in the case of Kazakhstan by Karatayev et al. (2021). Their findings posited the potential decrease in yield under the any future reduction in precipitation and occurrence of droughts. Sommer et al. (2013) estimates that rises in temperature and precipitation in winter may be beneficial for wheat production in Central Asian countries. In terms of water availability, observed climate shocks caused a 5–30% water flow decline in the Amu Darya and Syr Darya River basins, which are the main sources of irrigation for Central Asia (Ososkova et al., 2000; Chub, 2007; CAREC, 2011). Meanwhile, Radchenko et al. (2017) explored the water resource availability under the climate change impacts for the period of 2071–2100 in Central Asia. Temperature rise and accelerated glacier shrinkages could lead 12–42% decrease in summer runoff and 44–107% increase in winter-spring runoff. Because of the expected temperature increases and accompanied decreases in precipitation, numerous studies have also indicated that aridity is anticipated to increase extremely across the Central Asia, specifically in the countries with dry zones like Uzbekistan (IPCC, 2007; Lioubimtseva & Henebry, 2009; Christopher, 2017). Likewise, climate change could have a substantial impact on irrigation source and overall economic prosperity of Central Asian countries, as water scarcity has already become a strategic concern in the region (Didovets et al., 2021).

Located in the central part of Central Asia, Uzbekistan is characterized as dry and landlocked. The country has continental climate, which summers are hot and highest temperature reaches up to 50 °C, while winters are quite cold with temperatures of -35 °C (World Bank, 2009; FAO, 2012). Country receives between 95–1,000 mm annual precipitation on average, and it is even less than 100 mm in northwestern parts of the country (IPCC, 2007; Mirzabaev, 2013). The role and share of agriculture is the largest one in the structure of national economy, with a sectoral contribution of 28.7% to the country's national GDP and with 33.2% of the country's labor force employed in agriculture (SCRUZ, 2018; World Bank, 2018). Most notably, more than 49% of the country's population lives in rural areas, with roughly 26% of them fully engaged in agricultural production (World Bank, 2018). From 1953 to 2013, the mean temperature rose by 2.4 degree Celsius in Uzbekistan, resulting significant reductions in river flow and growing interest for irrigation in the republic (UNDP, 2011; Sommer et al., 2013; Bobojonov & Aw-Hassan, 2014). Due to a recent frequency of climate changes and growing water use from upstream producers, irrigated agriculture will con-

tinue to play vital role in the country's long-term sustainability (Franz et al., 2010). Accordingly, irrigation water shortages for agricultural purposes may also lead to significant welfare losses, including lower crop yields (Bobojonov and Aw-Hassan, 2014). In addition, changes in climate patterns may shorten total rain-fed agricultural production areas and alter the irrigation requirements.

Uzbekistan almost fully relies on irrigated agriculture, with about 85% of the cultivated land being irrigated. The major agricultural crops are cotton and wheat, which jointly account for about 75% in the total production of irrigated agricultural land (SCRUz, 2018). The agricultural transition in Uzbekistan was started in 1991 right after the breakup of Soviet Union and continued through the independence years. Transition was forwarded with gradual reforms in order to achieve food self-sufficiency and sustainable growth of agricultural production. Cotton production is not only essential for the country's total agricultural production, but it is also a main cash crop for the economy, contributing about 5.6% to national GDP (SCRUz, 2019). Cotton growing is one of traditionally inherited production type in Uzbek agriculture and it was also main source of needed hard-currency in the beginning of independence years of Uzbekistan (Kienzler et al., 2011). Recent policies on agrarian sector have proposed removing state quota from cotton growing and transforming it into a cluster system (World Bank, 2020). In term of food security issue, wheat was considered as leading strategic crop for the country and obtaining grain self-sufficiency through increased wheat production was put forward as major strategic concern of Uzbek's agricultural policy (Abdullaev et al., 2009). With results stemming from gradual agricultural reforms in the country, agricultural production received steady positive growth through the transition (Lerman, 2008; Abdullaev et al., 2009; Kienzler et al., 2011). However, due to unfavorable climatic conditions over the last two decades, agricultural productivity is still remaining lower and there were significant losses on crop yield, with more than 30% for cotton and 15% for wheat in the country (Müller, 2006; FAO, 2018).

As far as water availability, Bobojonov et al. (2012) assessed that a 30% decrease in an irrigation system in Uzbekistan could bring about a 4–17% loss in expected gross agricultural earnings during the period of 2010 and 2040 and a 35–55 per cent loss somewhere in the field of 2040 and 2070. A consistent ascent in mean temperatures, joined with a high demand for water sources, may present genuine difficulties to Uzbekistan's agricultural policies. Besides, Bobojonov et al. (2016) estimated time of arrival explored income and irrigation water use productivity under a climate shock in western Uzbekistan utilizing an incorporated strategy to observe a case that income ranches could fall by 25% with a 3.2°C temperature increment and a 15% diminishing in the water system. Farms with the downstream area might be paced much more chime, while certain harvests benefit from expanded vegetation periods under the safer temperature increments. Despite the existing literature, the majority of previous researches' findings were based on integrated assessment approaches. Furthermore, these studies mainly involved crop and climate models together for long-term *ex ante* assessments of the adverse consequences of climate-induced hazards on total output of different agricultural crops across the different regions of Central Asia. With perspective empirical evidence from Samarkand region of Uzbekistan, this study specifically contributes to regional knowledge on the combined impact of irrigation and climate factors for the first time.

3. Methodology

3.1. Study site

Located in the central-eastern part of Uzbekistan, Samarkand region was chosen for this analysis shown in Figure 1. The region occupies 3.7% of the country's total territory and about 12% of the total population of Uzbekistan lives in the region, with nearly 64% of them living in rural areas (SCRUz, 2019). Agricultural crop land of the region is about 432 thousand hectares, of which 249 thousand hectares is irrigated or

accounts for roughly 10% of the total irrigated land of the country and 183 thousand hectares are rain-fed as well (SCRUz, 2018). The economy of the region is agro-industrial oriented and region provides about 14% to total GDP of the republic. Agricultural sector plays a far greater role in the structure of gross regional production, contributing for more than 30% of total output (SCRUz, 2019).

The territory of Samarkand region lies on the main body of Zarafshan River Basin and region entirely utilizes the water sources of Zarafshan River for irrigation purposes (Hasanov & Ahmed Nomman, 2011; Sanaev et al., 2017). However, there is still inadequate water to supply the total irrigation needs of the region although 20% of the runoff water is reused for agricultural purposes. Furthermore, high level land salinization has already exacerbated the condition of irrigation requirements in northern parts of the region (Hujanazarov et al., 2014). Climate change brought additional dimensions upon these issues and the consequences of future climate scenarios may further strengthen water scarcities in the region.

The Samarkand region has a favorable climate for agricultural production and therefore it considered as main suppliers of agricultural commodities in the country (Sherzod et al., 2018). As shown in Figure 2, wheat and cotton production still dominate with a significant portion of about 40% and 21%, respectively, in the total agricultural production of the region (SCRUz, 2018). Therefore, the main scope of this research work centered on these particular crops.

Based on the climate, Samarkand region can be classified as follow: The northern and western parts having a continental climate, and the remaining parts (the center, south and east) displaying subtropical intra-continental climates. Both of these climates are characterized by hot and dry summers with partly cold winters. During the short winter periods frost may occur, with temperatures dropping down to -26°C, and in summer temperatures can reach +46°C. The region lies higher than 700m above sea level and receives between 310–365 mm of annual precipitation on average (SCRUz, 2019; UzHydro-Met, 2018).

Figures 3, 4 and 5 present the climate data from the Climatic Research Unit (CRU, 2018) and the World Bank (2018b), as well as the National Center of Hydro-Meteorological Service, for the annual cultivating seasons from 1982–2018. Accordingly, increases in average annual temperatures accompanied with minor changes in precipitation were observed for the last thirty years in the region. Since the year 2000, dramatic increases in spring and summer temperature and decline in precipitation was observed across the region. As is evident from the following Figure 5 (a, b), temperature increases have mainly occurred in spring and summer, which would have increased the risk of heat stresses for agricultural crops in the region. Not surprisingly, heat stresses caused by high temperature increases could be an important constraint to agricultural productivity and lead to losses in producers' total harvests (Sharma et al., 2008).

3.2. Data

The current agricultural production system includes three types of producers in the country, which private/commercial farmers (*fermer*¹) with average of 50 ha of land, households/small scale peasants (*dehqon*) having 1 ha of land on average and newly emerged clusters with quite large size of lands. Private/commercial farmers mostly produce cotton and wheat for state procurement targets and in return they are subsidized by inputs such as seeds, fertilizers, fuel etc. from the state (Sherzod et al., 2018). Households/small scale peasants are the main producers of cash crops but not specialized in cotton production. Households produce initially for their own consumption and for local and international markets as well. Clusters are recently established and specialized either on livestock or agricultural crops, whereas contains the processes from the production unit to exports.

¹ *Fermer* – is the local terminology for private/commercial farmers *Dehqon* – is the local terminology for household/small scale peasants

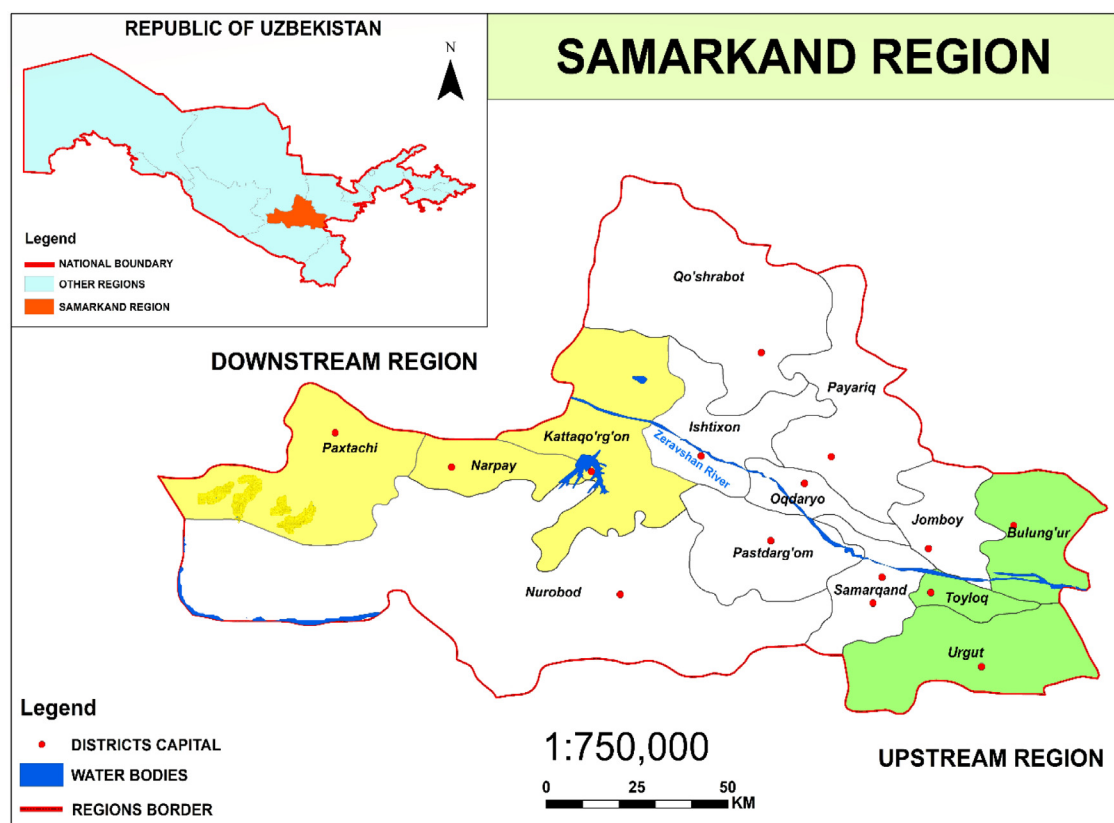


Figure 1. Map of Uzbekistan and the study area
Source: Authors using ArcGIS software 10.3

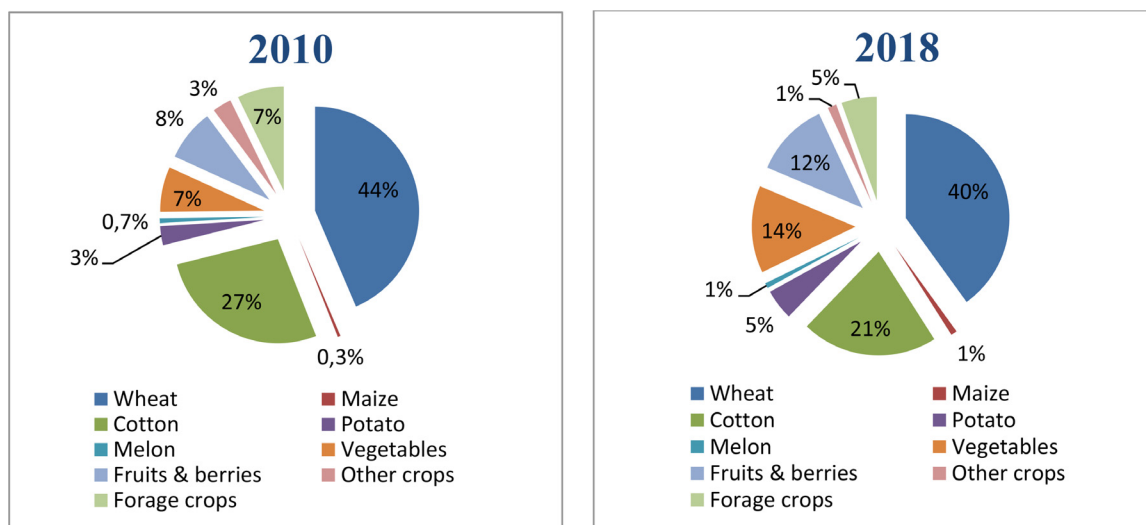


Figure 2. The structural composition of agricultural crops in Samarkand region
Source: The State Committee of the Republic of Uzbekistan on Statistics (2018); Authors' calculations

Although households are the main producers of export crops, the data on their performance is not available neither at cross-section nor at panel frame. Therefore, empirical framework was implemented utilizing farm level panel data 2013 to 2018, which included wheat and cotton-growing commercial/private farmers who provide regular annual reports to statistical agencies. The secondary statistical data at farm level was gathered up from the Statistical Department of the Samarkand region. The dataset includes only 2,135 of wheat and 1,141 of cotton-growing commercial farms located across the Samarkand region and

households are not included. According to the annual census of the Statistical Department (SCRUZ, 2020), currently total of 12,435 farms are operating at 14 districts in Samarkand region. Selected samples for the study represent one-fourth of the total farms from 11 districts where irrigated wheat and cotton production is common. Accordingly, the selected samples were chosen for this analysis due to their continuous farming performance during the study period and relatively higher contribution with higher yields to gross agricultural product of each district. Descriptive knowledge in details about the study area have been

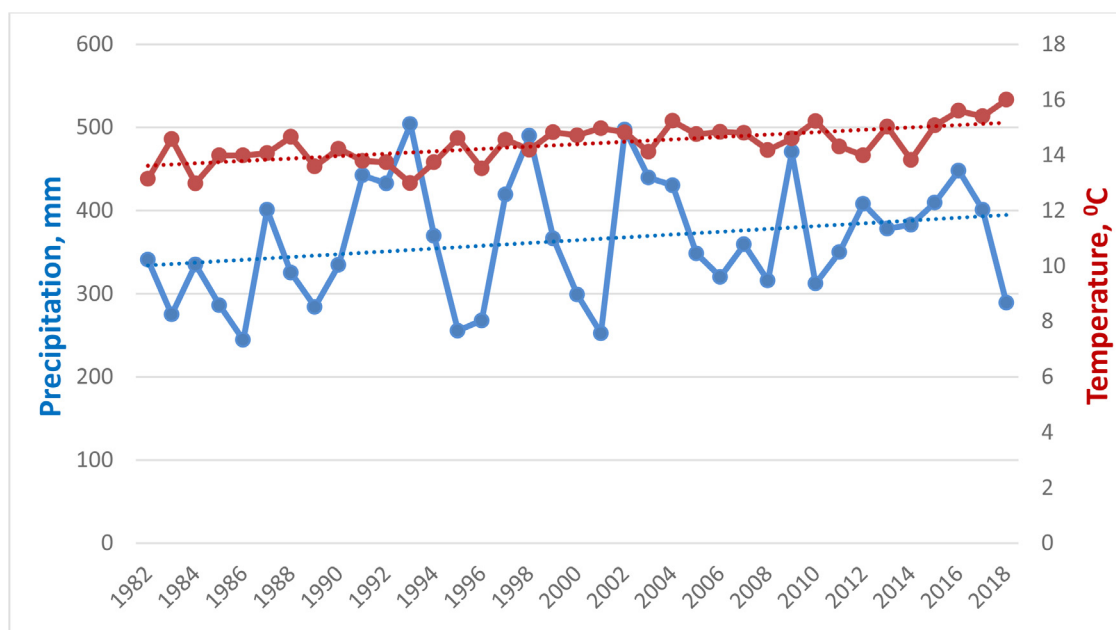


Figure 3. Annual mean temperatures and precipitation amount in the Samarkand region, 1982–2018

Source: Authors' own compilation based on data from the gridded time-series (TS) Version 4.01 (CRU, 2018) and the (World Bank, 2018b)

provided in previous section. Each dataset contains single outcome and multiple explanatory variables, whereas the weighted total yields of produced wheat and cotton in the samples was created as the outcome variable. Production inputs (independent variables) applied by both wheat and cotton-growing farms are similar, which are labor force (*LF*), seeds (*SD*), total amount of applied chemical fertilizers (*ChFer*) and irrigation (*Irrig*). All variables employed in production analysis were specified in quantitative units (kg/ha and m³/ha). As a reference, [Ahmed & Schmitz \(2011\)](#), [Mirzabaev \(2013\)](#), [Rahman & Anik \(2020\)](#) have also used similar variables in their studies.

Irrigation data at the district level was obtained from the interregional department of the Zarafshan Basin WUA (Water Users' Association) for the study years. The total amount of water used for each crop type per hectare was identified at the district level from the dataset and then incorporated into the regressions. As [Hsiao \(2007\)](#) and [Rahman and Anik \(2020\)](#) argued, panel data provides more precise model parameters and enables us to control for individual heterogeneity.

Daily data on weather variables (temperature and precipitation) for the region was obtained from the National Hydro-Meteorological Agency. Monthly climate data was extracted at a spatial resolution of 0.5 °C from the gridded Time Series (TS) Version 4.01 data from the Climatic Research Unit (CRU, 2018) and the World Bank (2018b) for the annual cultivating seasons from 1982 to 2018. As employed in past literature (e.g., [Lobell et al. \(2011\)](#)) the effect of environmental change on absolute yields of wheat and cotton developing ranches were evaluated, which included changes in average temperatures and precipitation from March to June, which is the primary term for winter wheat (the blooming and final development stage), and mean climate varieties from May to September for cotton.

3.3. Methods

There are various types of assessment methods and techniques, such as agronomic and integrated models, Ricardian models, econometric yield models and panel approaches, which are widely used within climate analyses worldwide ([Mendelsohn et al., 2006](#); [Cline, 2007](#)). Each method has its advantages and disadvantages based on their characteristics and functions as well. Agronomic models are appropriate for representing the complexities of climate change effects, such enable to con-

sider biophysical environment, management strategies, and crop production fluctuations ([Jones et al., 2003](#)). The basic feature of crop simulation models has already been proven in the context of yield prediction analysis. Nevertheless, these models treat management strategies as exogenous in estimations ([Schönhart et al., 2011](#)).

Nonetheless, there is an integrated assessment model often well-known as the Bio-Economic Farm Model (BEFM) ([Janssen & Van Ittersum, 2007](#); [van Delden et al., 2011](#); [Ihtiyor Bobojonov, 2021](#)). This model allows for the simultaneous integration of bio-physical changes and decision-maker's adaptive behaviors in various farming systems, while it is suitable for studying climate change consequences either at farm or sector level ([Keating and McCown, 2001](#)). Furthermore, even with limited data integrated models are capable of investigating the linkages between agro-ecological factors and production behaviors of farmers under the climate change scenarios ([Weersink et al., 2002](#); [Thornton, 2006](#)).

In climate change, econometric regression models can estimate the effects of weather variability on crop productivity ([Cabas et al., 2010](#)). Unlike crop models, econometric approaches can simultaneously combine socioeconomic and institutional factors with biophysical factors, indicating the benefits of these models. Accordingly, production functions ([Adams et al., 1999](#)) and the well-known Ricardian model are two widely used econometric methods ([Mendelsohn et al., 1994](#)). Using long-term historical/cross-sectional data, the Ricardian technique is more adaptive in capturing the effects of climate – related events on values of land resource or net income of agricultural producer at national or regional level. However, it cannot capture the adaptation adjustments of decision makers over the short-term ([Mendelsohn, 2008](#); [Mirzabaev, 2013](#)). Moreover, this method may face constraints in projecting future climate change consequences on agriculture at the farm level due to technological advances and CO₂ concentrations ([Bobojonov & Aw-Hassan, 2014](#)).

In this study, we considered a time-invariant frontier model ([Battese and Coelli, 1995](#)) with the panel approach as the most appropriate for empirical estimations based on two main reasons: a) the availability of agronomic and integrated methods in previous literature and b) unlike the Ricardian approach, the estimation methods have the advantage of controlling for unaccounted time-invariant heterogeneity among farms in the area of research. Land values are not included as an explanatory

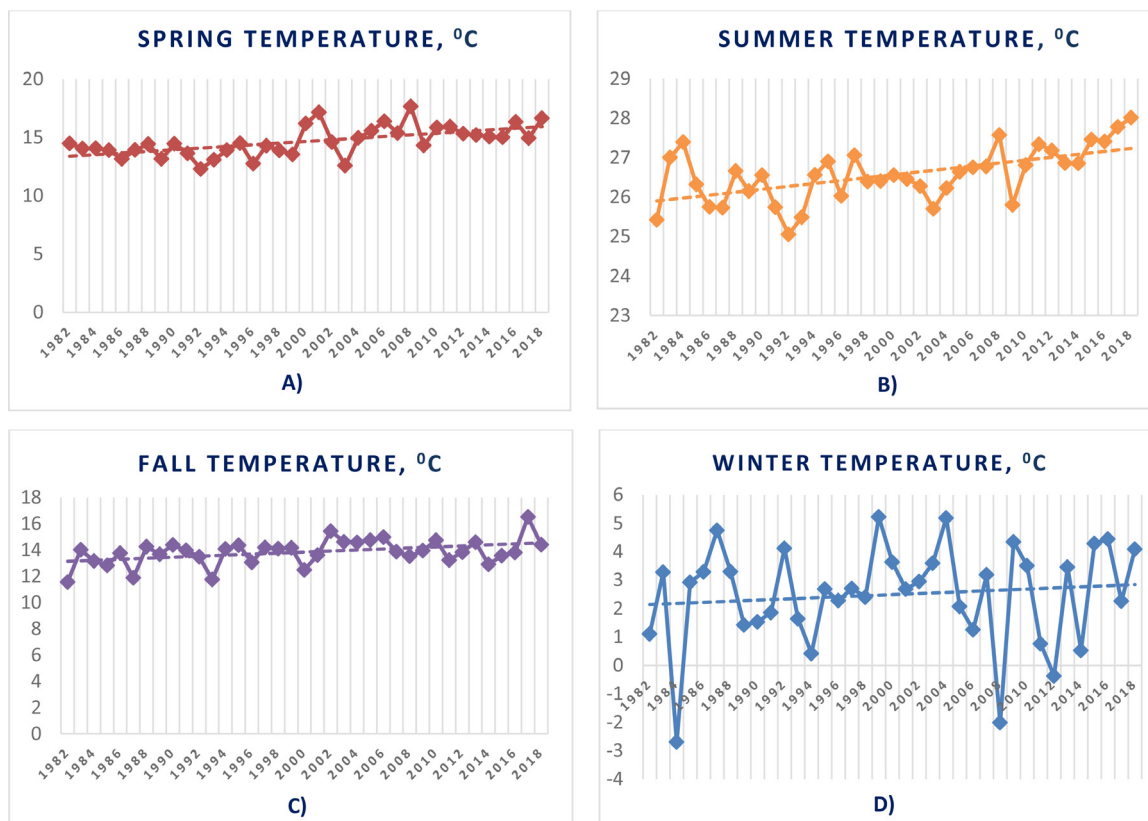


Figure 4. Seasonal mean temperatures in the Samarkand region, 1982-2018

Source: Authors' compilations based on data from the gridded time-series (TS) Version 4.01 (CRU, 2018) and the (World Bank, 2018b)

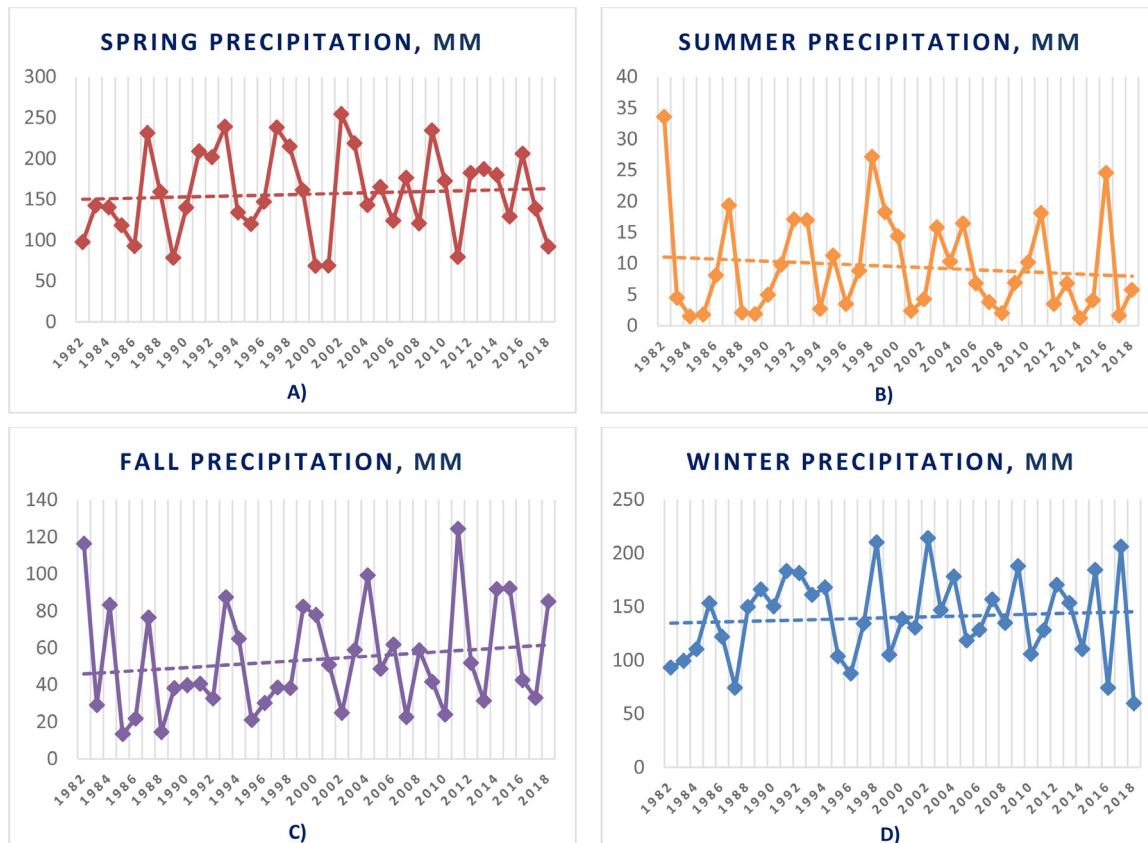


Figure 5. Seasonal mean precipitation in the Samarkand region, 1982-2018

Source: Authors' compilation based on data from the gridded time-series (TS) Version 4.01 (CRU, 2018) and the (World Bank, 2018b)

variable in the panel approaches because they reflect the effect of long-term climate rather than short-term weather variations. Further, according to Deschênes and Greenstone (2007) the panel model would offer more conservative climate change projections than Ricardian models.

Despite the interpretation of differential individual effects as inefficiency over time the role of unobservable individual heterogeneity in the estimation of stochastic frontier models is prominent. In order to implement the empirical framework, a Stochastic Frontier Approach (SFA), which was proposed by Aigner et al. (1977), was utilized. There are two types of frontier models for panel data, which are stochastic production and cost frontier models. Panel frontier model allows two various parametrizations of inefficiency term: A Time-invariant model and Battese-Coelli parametrization of time effects, while idiosyncratic disturbance term assumed to have normal distribution in both models (Battese and Coelli, 1995). The general stochastic frontier model for panel data has following specifications:

$$Y_{it} = \alpha_i + x_{it}\beta + \varepsilon_{it} \quad (1)$$

$$\varepsilon_{it} = U_{it} - V_{it} \quad (2)$$

$$V_{it} \sim N(0, \sigma_v^2) \quad (3)$$

$$U_{it} = u_i, u_i \sim N + (\mu, \sigma_u^2) \quad (4)$$

Where, Y_{it} is the output of i -th firm at t time, x_{it} is vector explanatory variables, ε_{it} is error term of stochastic model. Stochastic frontier models propose either output maximization or input minimization in production. Farm level panel data from 2013–2018 was utilized and dataset includes only commercial/private farms operating for state targets. During the timeframe of study, we distinguished that the land size for wheat and cotton-cultivation almost unchanged among selected farms and therefore we did not incorporate land as explanatory variable into analysis. The changes were only occurred with implementation of land optimization in 2019, while farmers became more bigger than previous time. In our case, wheat and cotton-growing farms produce for the state procurement targets of the country, while production units and the price of products are determined by the government. In return, farmers are subsidized for inputs, such as seeds, fertilizers and fuel (Abdullaev et al., 2009). Following Pitt & Lee (1981) and Battese & Coelli (1988), since the managerial ability of farms is unchanged during the timeframe of research work, the time-invariant production approach under the distributional assumptions was considered adequate for estimations. Furthermore, the interaction impacts of irrigation amounts and climate variables, such as mean temperatures and accumulated mean precipitation on total yields of wheat and the cotton-growing farms were estimated also estimated. Following Battese and Coelli (1995) the logarithmic form of stochastic frontier model is specified as follow:

$$\ln Y_{it} = \beta_0 + \sum_{j=1}^6 \beta_{1j} \ln X_{tji} + \sum_{j \leq k=1}^6 \beta_{2jk} \ln X_{tji} \ln X_{tki} + U_{it} - V_{it} \quad (5)$$

Where, the subscript i represents the i -th farm at t -time;

Y_i is the total yield, measured in kilograms;

X_1 is the logarithm of planted seeds, measured in kilograms;

X_2 is the logarithm of applied fertilizers, in kilograms;

X_3 is the logarithm of employed labor, measured in persons;

X_4 is the logarithm of applied water amounts, m^3/ha ;

X_5 is the logarithm of mean temperature, $^{\circ}C$;

X_6 is the logarithm of mean precipitation, mm;

V_i is an error term, which is related with random factors, not under the control of the farmer, to be independently and identically distributed as $N(0, \sigma_v^2)$;

U_i is the non-positive random variable independently distributed as truncations at zero of $N(0, \sigma_u^2)$ (Coelli, 2021)

An input-oriented approach was adopted, whereby total farm output and employed inputs were exogenously determined and climate factors were considered as additional external input variables (Kumbhakar et al., 2014). Importantly, the weather variables used were at small-scale rather than the provincial or country level.

3. Results

3.1. Summary statistics

As described in above material section, the farm level panel data was utilized in order to implement the empirical framework. First, the data set was obtained from the statistical department of Samarkand region including only more than 4 thousand of commercial farmers from 14 districts for the period of 2013–2018. Out of 2135 wheat and 1141 cotton-growing farmers were incorporated into analysis from 11 districts where irrigated agriculture is well developed. The remaining samples from 3 districts were excluded from dataset, which are rain-fed farmers mainly specialized to livestock and viticulture. Based on final dataset, the minimum, maximum and mean values of all output and input variables were calculated by authors using STATA 15 software package and was illustrated as descriptive statistics table respectively. Based on our dataset, Table 1 provides descriptive details about the dependent and independent variables used in our estimations. As we are able to judge from the table's information, on average, cotton-growing farms have a larger land size than wheat-growing farms, with a mean of 32,8 and 20,1 hectares, respectively, in the study area. Theoretically, cotton growing requires a more intensive labor force, as well as more fertilizers and irrigation than wheat. Wheat growing farms employed a labor force of 3,8 persons on average and cotton growing farms 7,2 persons. In terms of fertilizers and irrigation, farmers apply more water and fertilizers for cotton rather than wheat in the research area and the average planted seed amount is 214,1 kg/ha for wheat and 70,3 kg/ha for cotton growing. Accordingly, wheat yields are 4,304 kg/ha and cotton yields are 2,490 kg/ha on average in the region.

3.2. Climate change impacts

At first Wooldridge test (Wooldridge, 2010) for autocorrelation in the panel data series was implemented in accordance with empirical framework outlined in the previous section. The coefficients of the Wooldridge test for autocorrelation in the panel data strongly reject the null hypothesis, while justifying that there is no first-order autocorrelation in employed dataset. In addition, robust standard errors were calculated in order to ensure more reliable statistical inferences (Kezdi, 2003; Stock & Watson, 2008). A time-invariant frontier model was utilized to investigate the adverse effects of climate-induced extremes on total output of wheat and cotton growers. The detailed outcomes of the estimations are reported in Table 2. According to the table statistics, the coefficients of the sigma square were confirmed to be statistically significant, respectively. This implies that the empirical approach is appropriate for the data and explains the good relationship between the outcome and predictor variables.

All inputs applied in production have a beneficial effect on the total outputs of wheat and cotton-growing farmers. Among the input variables, the coefficient of fertilizers and irrigation is highest for cotton growing farms versus wheat farmers, while it was found to have a significant beneficial effect on both wheat and cotton yields. This could be because cotton is a more water consuming crop compared to wheat and the effective application of fertilizers such as additional manure could be a good solution in order to maintain the natural moisture of soil during the drought seasons. Accordingly, other production inputs such as seeds and labor have also beneficial effect on total outputs of both farmers engaged in wheat and cotton production in the research area. The coefficients of all predictor variables utilized for the analysis were determined at 1%, 5% and 10% significance levels, respectively.

Table 1
Descriptive statistics of the variables involved in the analysis

Variables	Measurement unit	Mean	Stand. Dev.	Min.	Max.
Wheat-growing farms					
Wheat yield	kg/ha	4,304	10,57	2,100	7,480
Land size	ha	20,10	12,42	6,00	220
Seeds	kg/ha	214,10	21,24	170	300
Chemical fertilizers (nitrogen)	kg/ha	253,80	55,02	100	520
Labor force	persons	3,80	2,14	2,00	25
Irrigation	m ³ /ha	8738,4	2580,9	5600	13040
Mean temperature (March to June)	°C	18,10	1,72	13,60	21,30
Mean precipitation (March to June)	mm	116	0,51	30	240
Number of observations	2135				
Cotton-growing farms					
Cotton yield	kg/ha	2,490	5,32	1,400	4,070
Land size	ha	32,80	18,18	8,00	233,70
Seeds	kg/ha	70,30	8,421	55	90
Chemical fertilizers (nitrogen)	kg/ha	493,30	70,55	370	645
Labor force	persons	7,20	3,01	3,00	27
Irrigation	m ³ /ha	11821,50	2176,74	8150	15229
Mean temperature (May to September)	°C	26,20	0,90	24,50	28,50
Mean precipitation (May to September)	mm	19	0,14	3,00	60
	1141				

Source: Authors' calculations

Table 2
Detailed results of the time-invariant frontier model

Variables	Parameters	Wheat-growing farms	Cotton-growing farms
Frontier function			
Constant	β_0	5,85 *** (0,138)	- 8,22 *** (0,418)
Seeds	β_1	0,66 *** (0,017)	0,16 *** (0,017)
Fertilizers	β_2	0,11 *** (0,009)	0,29 *** (0,018)
Labor	β_3	0,03 *** (0,006)	0,06 *** (0,008)
Irrigation	β_4	0,09 *** (0,016)	0,46 *** (0,021)
Mean temperature	β_5	- 0,57 *** (0,034)	2,96 *** (0,115)
Mean precipitation	β_6	0,03 *** (0,005)	- 0,03 *** (0,004)
Seeds x Seeds	β_{11}	0,33 *** (0,009)	0,08 *** (0,009)
Fertilizers x Fertilizers	β_{22}	0,05 *** (0,005)	0,14 *** (0,009)
Labor x Labor	β_{33}	0,02 *** (0,003)	0,03 *** (0,004)
Irrigation x Irrigation	β_{44}	0,05 *** (0,008)	0,23 *** (0,011)
Seeds x Fertilizers	β_{12}	0,13 *** (0,010)	0,31 *** (0,020)
Seeds x Labor	β_{13}	0,05 *** (0,006)	0,07 *** (0,008)
Seeds x Irrigation	β_{14}	0,31 *** (0,018)	0,23 *** (0,022)
Seeds x Mean temperature	β_{15}	- 0,12 *** (0,027)	- 0,24 *** (0,035)
Seeds x Mean precipitation	β_{16}	0,02 *** (0,005)	- 0,008 ** (0,004)
Fertilizers x Labor	β_{23}	0,03 *** (0,006)	0,07 *** (0,008)
Fertilizers x Irrigation	β_{24}	0,68 *** (0,011)	0,35 *** (0,019)
Fertilizers x Mean temperature	β_{25}	- 0,57 *** (0,018)	0,12 *** (0,036)
Fertilizers x Mean precipitation	β_{26}	- 0,006 (0,005)	- 0,007 ** (0,004)
Labor x Irrigation	β_{34}	0,80 *** (0,010)	0,84 *** (0,008)
Labor x Mean temperature	β_{35}	- 0,74 *** (0,012)	- 0,74 *** (0,014)
Labor x Mean precipitation	β_{36}	- 0,01 ** (0,005)	- 0,02 *** (0,004)
Irrigation x Mean temperature	β_{45}	0,79 *** (0,009)	0,94 *** (0,007)
Irrigation x Mean precipitation	β_{46}	0,01 ** (0,005)	- 0,03 *** (0,003)
Mean temperature x Mean precipitation	β_{56}	- 0,05 *** (0,08)	- 0,13 *** (0,006)
Variance parameters			
Sigma-squared	σ_s^2	0,077*** (0,002)	0,056*** (0,023)
Gamma ratio	γ	0,392*** (0,015)	0,473*** (0,020)
Log-likelihood function	llf	- 202,9652	1399,5421
Number of observations	n.ob.	2135	1141

Note: Standard errors are robust to heteroskedastic and contemporaneous correlated disturbance and ***, **, * indicates 1%, 5% and 10% significance level, respectively. **Source:** Author's own calculations

In addition, the direct impacts of the climate variables were also estimated on the total outputs of farms in the study region. In particular, daily temperatures and rainfall are also important factors for the yields of agricultural crops and may have either a beneficial or harmful effect on farm performance. The empiric model results revealed that the influence of climate factors differ by crop type across the study regions. An increase in warming is harmful for wheat farmers, while the production of cotton-growing farmers suffers from excessive rainfall.

Empirical estimations were implemented using time-invariant frontier model, while the impacts of mean temperature and accumulated precipitation during the months of March-June for wheat-growing farmers' yield and the same weather variables from May to September for cotton-growing farmers' yield were estimated and results are illustrated in Table 2. Furthermore, a 1 °C increase in the mean temperature between March to June may lead to total yield losses of up to 60% on wheat-growing farms, while precipitation has a significant positive ef-

fect. Nonetheless, excessive and erratic rainfalls may damage crops and cause plant diseases. In contrast, the temperature effect was found to be beneficial for cotton-growing farmers, but excessive rainfall during the months of May–September may lead to 3% losses on the total yields of cotton-cultivating farms in Samarkand region. Along with this, the joint effects of the climate variables such as mean temperature and accumulated precipitation were also estimated under same technique and it was found that both of wheat and cotton-growing farmers may suffer from temperature increases and excessive precipitation in the distant future.

Accordingly, the interaction effect of irrigation and mean temperature has highly significant positive impacts on the total yields of both wheat and cotton growing farmers in the region. This means that as temperatures increase, the importance of water also increases for both crops during the vegetation period. Moreover, farmers with sufficient irrigation are more resistant to climate threats, especially in countries where water scarcities already exist due to climate and other external shocks.

4. Discussions

Uzbekistan is highly sensitive to climate consequences due to its dry continental climate and scarce water resources. The occurrence of climate emergencies posed gradual disappearance of Aral Sea and deteriorated the conditions of water-related issues for irrigated agriculture of the country. As per recent studies, there has been decline in water supplies and yield losses due to climate extremes (Radchenko et al., 2017). In this perspective, interaction impact of irrigation and climate change on the performance of farmers was investigated through Climate-oriented empirical framework in Samarkand region of Uzbekistan. Estimations were implemented using farm-level panel data that included 2,135 samples from wheat- and 1,141 samples from cotton-growing farms, along with input variables for the most important production inputs (seeds, fertilizers, labor force and irrigation). The empirical findings revealed that farmers are highly sensitive to climate-related factors, but also to factor inputs such fertilizer use and irrigation. According to statistical inferences, all of the production inputs used have a considerable beneficial impact on the total outputs of farms growing wheat and cotton. Starting with fertilizers, the coefficients were found to have considerable positive effects on wheat and cotton yields. This may imply that farmers may be able to capture yield increases through the effective application of fertilizers when climatic shock occurred. Furthermore, improving farmers' access to fertilizers through government agencies could be one of the crucial adaptation measures against future climate shocks. Similar results were also estimated by Ahmed & Schmitz (2011) Kumar (2014) and Gupta et al. (2014).

In addition, the impact of weather variables such as changes in average temperatures and precipitation between March to June for the case of wheat farmers and similarly during the months of May–September for cotton farmers were estimated. The empirical findings of this study, which is the harmful effects of climate factors (increases in mean temperatures and precipitation) on the total yields of the two crops are consistent with the results of previous research by Ali et al. (2017) and Schierhorn et al. (2020). As indicated in the results section, an increase in mean temperature during the months of March–June is harmful for wheat-growing farmers. Wheat production is highly sensitive to temperature increases in the spring time, especially during the processes of flowering, grain-filling and the last phases of maturity (Hazratkulova et al., 2012). The optimal temperature during the flowering phase for winter wheat is considered to be between 25–30°C and temperatures above 30°C result in heat stress—and even five days of heat stress is sufficient enough to cause significant reductions in total yields (Hazratkulova et al., 2012). Precipitation, on the other hand, has a significant and beneficial impact. However, excessive/unpredictable rainfall can cause flooding and foster the spread of plant diseases under the condition of non-linear relationship between the crop yield and climate-related factors (Mirzabaev, 2013; Sommer et al., 2013). Conversely, the influence of

temperature between May to September was found to have a beneficial and significant effect on the total outputs of farms engaged in cotton-growing, but their production could suffer from excessive rainfall. Theoretically, cotton yields are not directly related to the amount of precipitation received during the summer and, therefore, any additional amount of rainfall or erratic patterns may damage the total yields of farms engaged in cotton growing. Cotton is more heat lover plant as based on its biological feature (Yilmaz et al., 2021). The increase in temperature is beneficial for the growing and maturing phases, but only together with sufficient irrigation. Temperature increase alone could damage the plant and lead yield losses in bottom. Therefore, the role sufficient irrigation is vital on the potential benefits of cotton-growing farmers in summer season. Furthermore, the interaction effects of temperature and precipitation levels were also found to have a considerable adverse impact on total yields of wheat and cotton farms in the Samarkand region.

When it comes to irrigation, the scarce water resources have already hampered agricultural production in the country. The issue depends not only on the availability of water, but directly interrelated with poor irrigation systems and frequent consequences of climate patterns. This implies that water scarcity has already become an urgent issue for the agricultural producers and having information/knowledge about future changes of water availability under climate changes is essential for the agricultural sector's long-term sustainability in Uzbekistan. Similar to the findings of Charles (2014) and Kumar (2014), irrigation amounts were shown to have a beneficial and highly significant effect on the overall outputs of farms engaged in wheat and cotton cultivation in the region. Furthermore, the interaction effects of irrigation and climate factors were observed to have a highly substantial favorable influence on both farms' total yields. Thus, we can argue that the importance of irrigation increases further as the mean temperature rises.

To summarize, farms with adequate water and proper irrigation system are more resistant to climate threats, and irrigation might be one of the country's most essential and effective adaptation measuring strategy on the basis of future climate challenges. Agricultural production, on the other hand, may suffer even more due to a lack of internal renewable water resources and inefficient use in the near future. Therefore, adaptation/mitigation-oriented strategies/pathways and the adoption of innovation-based new technologies in sustainable irrigation systems are needed in order to combat the consequences of future climate-induced hazards.

5. Conclusion

Climate change projections were reviewed, and the effects of weather variables and irrigation on farm productivity were assessed in the context of this research work. More specifically, the effects of weather variations and irrigation water application on total yield of wheat and cotton growing farms in Samarkand region were studied. A key empirical finding of this research work is that climate change impacts differ by crop type across the region. An increase in warming is harmful, but precipitation has a beneficial effect on the production of wheat farmers, while the production of cotton-growing farmers suffers from excessive rainfall. The interaction impacts of irrigation amounts and climate variables were found to have highly significant effects on the total yields of wheat and cotton-growing farmers, indicating that farms with sufficient irrigation systems are more resistant to climate threats. However, farms that irrigated may suffer from water shortages due to inefficient water use, increased warming and declining water resources in the near future. Therefore, policies that boost and improve irrigation management and encourage the adoption of water saving technologies in agricultural production should be considered. All in all, we suggest further studies with large scale datasets containing other crop types and covering longer periods to provide more valuable insights and implications for policymakers regarding increasing the resilience of agricul-

tural producers to future weather extremes in the Samarkand region of Uzbekistan, Central Asia and beyond.

Declaration of Competing Interest

The authors declare that there is no potential conflict of interest

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