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Climate Change Impacts and Agriculture: Empirical Evidence from Zarafshan River Basin, Uzbekistan

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Abstract

Climate change is becoming one of most disruptive phenomena for the agriculture of Central Asian countries, particularly for the predominantly rural communities. Nonetheless, the consequences of climate changes are still remaining uncertain and aridity is going to increase further in arid zones of the region, like in Uzbekistan. Agriculture as being an important sector for national economy is highly vulnerable to climate shocks and predicted future climate consequences may pose severe challenges to the resilience of Uzbek agricultural system, especially in terms of food security and income stability of rural producers. In this context, by aggregating both climatic and agricultural data we proposed to review the climate projections through agricultural transition and to analyze the impact of climate change (temperature and rainfall) on wheat yield for the first time in three regions of Uzbekistan, where irrigated agriculture has developed in Zarafshan River Basin. In this study district level panel data employed and analysis was implemented using Fixed effect model. Empirical findings revealed that, annual temperature has positive influence on wheat yield in short run. However, wheat farmers may suffer in distant future from increased temperature on their production. The annual precipitation amount has positive relation with production. In terms of seasonality changes, increase in temperature was found to have significant negative impact in all seasons. Contrary, precipitation has significant positive influence in all seasons except summer in the regions of Zarafshan River Basin.

Keywords

Climate Change, Agricultural Transition, Wheat Yield, Zarafshan River Basin

1. Introduction

The intensity, frequency and patterns of climate events are changing rapidly around the world and consequences differ in different countries [1, 2]. In particular, agriculture is most vulnerable to climate changes in developing countries although their contribution is less to annual global carbon dioxide [3, 4]. The occurrence of these phenomena is not only related with nature but due to human activities, the level of greenhouse gas emissions reached its peak point and the world is not only suffering from increased warming but frequently experiencing the erratic rainfalls and other climatic events [2, 5]. The consequences of such climatic shocks had already adverse impacts on agricultural production, food security and income stability of rural livelihood, [6, 7].

Central Asian countries are particularly vulnerable to climate changes due to its heterogeneous geography, dry continental climate, agriculture-based rural economy and water scarcities [8]. The climate of the region has already been changing rapidly and exceeding than global average [2, 9]. Most of future climate projections indicate increase in temperature by 3-4°C in Central Asia accompanied decrease in precipitation, water shortages and heat stresses during the vegetation period of agricultural crops [10]. In turn, agricultural production may suffer greatly from seasonality changes and availability of water sources for irrigation. Temperature and precipitation dynamics are key climate factors not only for rain fed areas, but availability of reliable irrigation water is becoming an additional important and related risk factor for irrigated areas as well. Changes in climate may increase these risks even further, while without adaptation, increased climate volatility may have a negative impact on agricultural production and livelihoods of rural communities in many parts of Central Asia [11]. The findings of some studies also indicating extremely increases in aridity across the region, especially in arid zones like Uzbekistan [8, 12, 13].

To The impact of climate change on agriculture and rural livelihood is studied broadly by numerous scientists in various cases around the world. Higher minima and maximum temperature increase accompanied decline in precipitation in the context of climate change was observed and it predicted to further increase with extreme consequences on agriculture for the late of 21th century in Central Asia [2, 14]. Climate change with the weather shocks are widely considered to be one of the important sources of price volatility in developing economies [15]. Increased price volatility for agricultural commodities has long been argued to exacerbate poverty levels, particularly in poor developing countries [16, 17]. Nelson et al. [18] projected that climate change may have negative effects on the eradication of child malnutrition in Central Asia. While, Parry et al., [19] assessed the biophysical impacts of climate change on crop production (wheat, maize, rice and soybean), where cereal yields were estimated to drop by between 2.5% -10% and 10%-30% under 2030 and 2050 scenarios. Furthermore, Sommer et al. [20] found that climate simulations like temperature increase during the flowering period of irrigated wheat posed high risk for flower sterility and reductions in total yield in the southern part of Central Asia.

Despite the existing literatures, most of previous studies explored the impacts of climate change based on integrated and agronomic approaches in the region. However, there is still limited studies conducted the impacts of climate change on agricultural production by using econometric approaches in the case of Zarafshan River Basin, which is one of main supplier of agricultural products in Uzbekistan. Therefore, we proposed to review and analyze the impacts of changes in climate on total output of farms operating in the regions of Zarafshan River Basin. The contribution of this study to the existing literature is twofold. First, we discuss and review the climate projections through agricultural transition in study area. Secondly, by aggregating both climate and agricultural data we investigate the impacts of climate change on wheat production.

2. Climate Change and Agricultural Transition in Uzbekistan

The role of agriculture is vital in many developing countries in terms of food security, rural livelihood and employment. The contribution of agricultural sector to national GDP of Uzbekistan is 25.5%, and employs more than 33% of total labor force of the country [7]. Most importantly, more than 49% population of the country is living in rural areas and about 26% of them are directly associated with agricultural production (World Bank, 2019). Cotton and wheat are the main crops, while recent policies were mostly oriented to support fruits and vegetable growing subsectors in order to improve the export potential of agricultural sector [21].

Uzbekistan has forwarded gradual transition from planned to market-oriented economy through agricultural reformations, including specialization, farm restructuring, land ownership, market liberalization, production efficiency and supporting market infrastructure from the beginning of independence years [22, 23, 24]. The undertaken gradual reformations were mostly addressed to change property rights in agricultural sector so as to improve farm income through increasing the volume of agricultural production [25, 26]. As shown in Figure 1, there is gradual positive growth on gross agricultural production in the country. In particular, there is rapid increase in wheat and vegetable production, while country has ensured its self-sufficiency in terms of agricultural production through the agricultural transition.

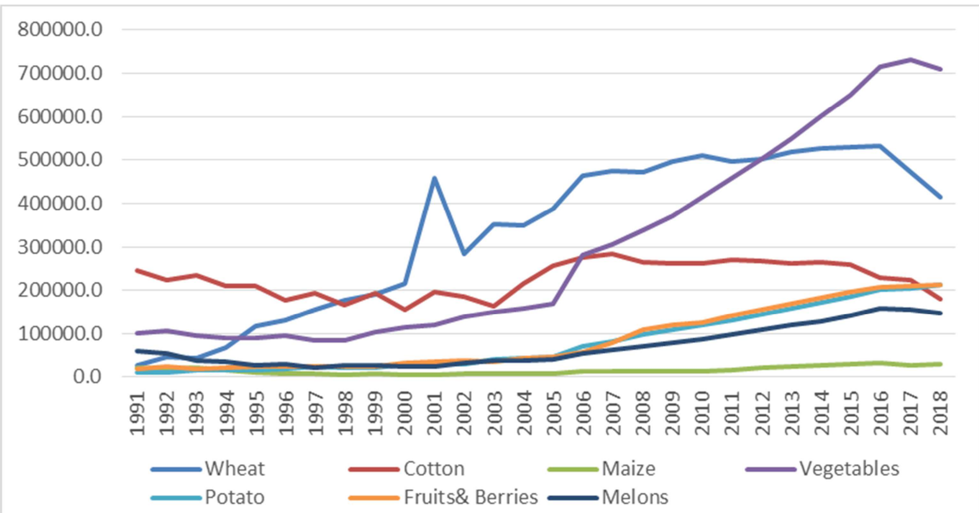

Figure 1. *Dynamics of gross agricultural production for the period of 1991-2018 in Uzbekistan.*

Source: [27]

Uzbekistan includes into territory of Central Asia, where located in central part with arid and semi-arid areas. Country characterized with dry continental climate which by high temperatures up to 50°C during hot summers and cold winter temperatures by -350°C [21, 28]. Annual mean precipitation ranges between 95-1000 mm, while north-western parts of the country receive less than 100 mm [11, 12]. The average air temperature has already risen by 2.4°C in Uzbekistan during the past period and this lead significant decrease on water flow from rives as well as increased demand for irrigation across the country [20, 29, 30]. Irrational use of natural resources (land and water) during the Soviet Union time have caused several problems such reduction in water sources and land degradation with high level of land salinization by up to 50-60% in Uzbekistan [31, 32]. The consequences lead reductions of cropping areas in irrigated lands and caused higher rates of poverty in rural communities [28]. Along with these, changes in climate patterns (frequent droughts, erratic rainfalls) becoming additional challenge to agricultural production and increasing the vulnerability of rural producers mainly located in semi-arid and arid zones of the country. Due to recent frequency of climatic changes and increased water consumptions of upstream users, the role of irrigated agriculture is remaining vital in the future sustainability of the country [33]. Reduced irrigation water availability for agricultural purposes may cause high level of welfare losses including reduced crop yields in Uzbekistan [29]. For example, droughts in 2000-2001, 2007-2008, 2010-2011 and 2018, damaged almost all types of agricultural crops and rain-fed farmers almost entirely lost their harvests [11].

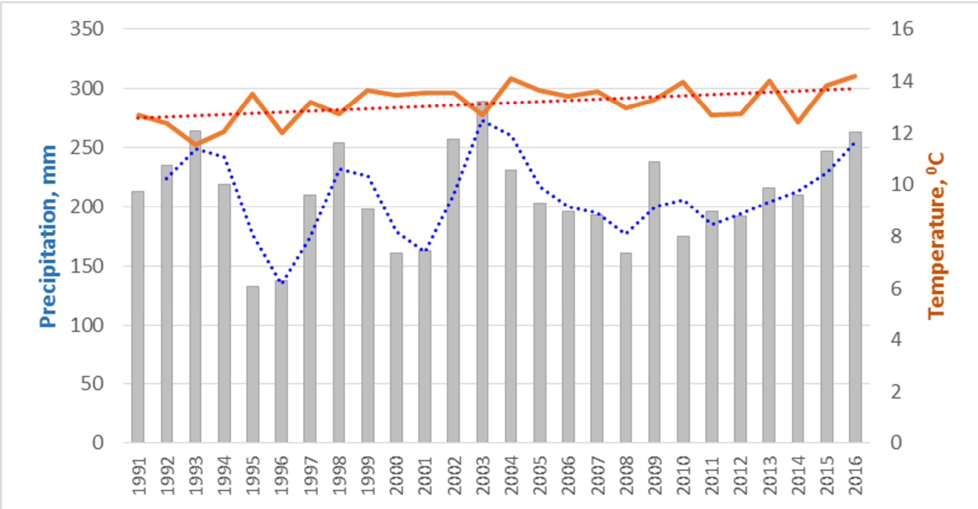

Figure 2. *Annual changes on average temperature and precipitation in Uzbekistan, for the period of 1991-2016.*

Source: Author's own completion based on data from the gridded time-series (TS) Version 4.01 data of the Climatic Research Unit (CRU) https://crudata.uea.ac.uk/cru/data/hrg/

Figure 2 represents the changes in dynamics of annual mean temperature and precipitation for the period of 1991-2016 in Uzbekistan. Accordingly, there were perceptible increases in mean annul temperature with more than 1°C degree and slight changes on annual mean precipitation during the last three decades (since the independence years). Along with this, temperature increase is mainly occurring in spring and fall seasons accompanied by reduction in precipitation amount. The continuous trends of such events may pose additional threats to agricultural production, especially for the crops like wheat which productivity is mainly depends on seasonal weather variations.

In all, the sustainability and development of agricultural sector mainly relays on several factors acting at national and global scales. At local scale, the agricultural production mostly depends on endogenous factors such as the availability and condition of natural resources (soil and water) as well as socio-economic factors (production resources, infrastructure etc.). At global scale, the performance of agricultural sector under existing endowments can be affected by exogenous drivers, which cannot be managed locally such as market/policy changes and climate changes [34].

3. Material and Methods

3.1. Study Area

In this study, empirical analysis was implemented in the regions of Zarafshan River Basin. Zarafshan River Basin is one of origin place in Central Asia in terms of agricultural development and main source of potable water for the regions of Zarafshan valley [35]. More than 8 million people or 1/4 part of the country's whole population are living in Zarafshan valley, while a water resource per capita is about 1050 cubic meters per year [36, 37]. The Zarafshan river is formed in the territory of a neighboring country with Tajikistan and considerable part of the river basin is in the territory of Uzbekistan. The length of the Zarafshan river is 781 km and the drainage basin area is 143 000 km^2 in

Uzbekistan site [38]. The map of the Zarafshan river basin in the territory of Uzbekistan is in Figure 3.

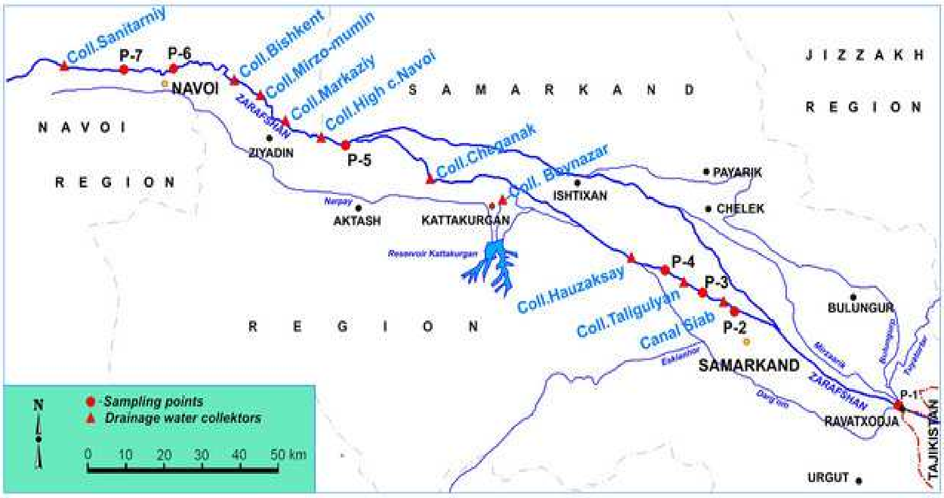

Figure 3. *The map of Zarafshan River Basin.*

Source: Adopted from the open sources of GIZ in Uzbekistan

The irrigated lands of the Zarafshan River Basin in the territory of Uzbekistan located mainly in two administrative provinces, which Samarkand region in upstream and Navoi region in downstream part. In addition, partially includes the territories of the Jizzakh and Kashkadarya provinces [36]. Among rivers in Central Asia, Zarafshan river is considered mostly affected due to irrational use of water sources, poor drainage network as well as intensified climate changes. Along with these, inefficient use and poor management of water sources for irrigation, poor drainage system and frequent droughts caused high level of land degradation and losses on agricultural output, particular regions located in downstream part of Zarafshan river basin [35].

3.2. Data

In this study, panel data for the period of 2000-2018 on wheat production at regional level was utilized for an analysis. Secondary data for agricultural production was obtained from the yearly book of the State Statistical Committee of the Republic of Uzbekistan. Dataset formatted with single output and single input variables. Within our study the average yield of wheat at district levels were merged into single regional scale and created as dependent variable in the analysis. The average wheat yield was 3980 kg/ha and rated with minima 1568 kg/ha to maxima 5830 kg/ha in the regions of the basin. Climate variables, such daily data on temperature and precipitation for the regions of Zarafshan river basin was obtained from the national center of hydro-meteorological services. Additionally, monthly climate data (annual temperature and precipitation) was extracted at a spatial resolution of 0.5° from the gridded time-series (TS) Version 4.01 data of the Climatic Research Unit (CRU) for the yearly growing seasons from 1991 to 2016 (https://crudata.uea.ac.uk/cru/data/hrg/). As utilized in previous literature [11, 39], the accumulated mean annual temperature and precipitation treated as independent variables so as to analyze the impact of climate variations on average wheat yield in the regions of Zarafshan river basin. Additionally, the quadratic forms of the weather variables (annual mean temperature and precipitation) was incorporated into regressions so as to explore the impacts of climate trends for the long-term.

3.3. Statistical Model

Climate change impacts can be analyzed by several types of assessment methods, such agronomic models, integrated models and econometric models as well [40, 41]. Each model has its pros and cons aspects based on their functions. Agronomic models are mainly suitable to capture the complex effects of climate changes, which simultaneously covers the biophysical environment, management practices and climate variation on crop yields [42]. The advantages of crop simulation models were already proven in yield prediction analysis, but models treat the management practices as exogenous in assessments [43].

Integrated assessment models are also well-known [44, 45]. While this model is capable to capture the simultaneous combinations of bio-physical changes and adaptation behavior of various farming systems under the climate change scenarios even with restricted data availability [43, 46]. The effects of weather variables in the context of climate change on crop yields can also be captured by statistical regression models [47, 48]. Unlike crop models, econometric regression models could incorporate socio-economic and institutional factors upon biophysical variables (e.g. soils, temperature and precipitation, the length of the growing period).

In this study, we used panel regressions in order to estimate the impacts of climate changes on crop yields. The literature broadly distinguishes the two most common panel approaches

Random effects (RE) and Fixed effects (FE) [49, 50]. Following Deschenes and Greenstone [51], panel model provides more conservative estimates of changes in climate trends. A Hausman test was carried out so as to ensure the true model specification, while there was no correlation found out between region-specific effects and farm output. Accordingly, null hypothesis was rejected and fixed effects (FE) model was considered as most appropriate approach for an analysis [49, 52]. In addition, the estimation method could also provide the advantage of controlling unobserved time-invariant heterogeneity by year fixed effects in study area. We used following form of the fixed effect model:

$$Y_{it} = \alpha_i + \beta_i + \sum \varphi_i (\omega_{it}) + \varepsilon_{it} \quad (1)$$

Where,

Y_{it} is the wheat yield for the region i at time t;

α_i is the fixes effect of the provinces;

β_i is the country fixed effects;

φ_i is the effect of weather;

ω_{it} is the vector of weather variables;

ε_{it} is the error term.

Furthermore, Wooldridge test [53] was carried out in order to test for autocorrelation in panel data series. Accordingly, null hypothesis was not rejected and concluded that, the data does not have first-order autocorrelation. Dependent variable was transformed into logarithmic form so as to make more price interpretations.

4. Results and Discussions

Climate change is becoming widespread and challenging agricultural sector almost entire the world. Likewise, agricultural production is highly sensitive to climatic events in the countries of Central Asia due to dry-continental climate and water scarcities. Based on the findings of previous studies, the climate regimes have been changing rapidly even with more than global mean and predicted to further increase in the region, especially in arid zones like Uzbekistan. The consequences of climate trends caused high level of reductions in water flow from the rivers, which main sources for irrigation in the country. Moreover, the overall consequences of expected climatic threats may pose severe challenges to the resilience of Uzbek agricultural system, especially in terms of food security and economic well-being of rural producers. In this contexts, the impact of climate changes, such particular changes in weather variations on wheat yield was estimated in the regions of Zarafshan river basin. The detailed results of fixed effect model are given in table 1.

As reported in results table, the calculated coefficient of R square was equal to 0.64, while indicating the model fits to dataset and statistical inferences could be reliable in order to offer valuable implications against future climate trends in study region. Accordingly, annual mean temperature had positive and significant influence on wheat yield in the regions of the basin. However, squared term coefficienct of the temperature was found negative and statistically significant, while farmers may suffer from increased temperature trends on their production in long-term. The coefficient of precipitation is positive for the crop yields respectively. In terms of seasonality, temperature variations had negative significant impacts, indicating an increase in temperature may have negative influence to crop yield. As Sommer et al., [20] and Hazratkulova et al., [54] studied, wheat production is very sensitive to temperature variations, such increase in warming could be beneficial to wheat growth during the winter but may pose high risk for flower sterility and reductions on total yield in spring, which is most important period for the flowering phase of irrigated wheat. Accordingly, precipitation had positive and significant effect on wheat yield in all seasons during the study period. However, it should be considered that the relationship between crop yields and weather variables are non-monotonic, while excessive and erratic rainfalls may cause flooding and create favorable conditions for plant diseases [11, 20].

Table 1. *Detailed results of panel regressions. (Dependent variable: wheat yield in log form).*

Variables	Coefficients	Standard errors	Confidence interval - 95%	
Temperature				
Winter	- 0.6179518**	0.2302173	-1.082549	- 0.1533545
Spring	- 0.5790169**	0.2253344	-1.03376	- 0.1242736
Summer	- 0.4996901**	0.2301543	-.9641602	- 0.03522
Fall	- 0.590514**	0.2312039	-1.057102	- 0.1239256
Precipitation				
Winter	0.0033848*	0.0018786	- 0.0004064	0.0071761
Spring	0.0051833**	0.0019278	0.0012928	0.0090739
Summer	0.0019808	0.0036002	- 0.0052848	0.0092464
Fall	0.0039289**	0.0018725	0.0001501	0.0077078
Annual mean temperature	4.905716***	1.344949	2.1915	7.619932
Annual mean precipitation	- 0.0029776	0.0024078	- 0.0078367	0.0018815
Temperature squared	- 0.0880179***	0.0273426	- 0.1431975	- 0.0328382
Precipitation squared	1.2501348	2.0142347	-3.9304426	4.1804943

*** $p<0.01$, ** $p<0.05$, * $p<0.1$, Prob > chi2 =0.0000 Number of observations =57, Number of panels = 3, Time periods= 19. Source: the author´s calculations

In all, the climate trends had overall positive impacts on wheat yields from 2000 to 2018 years in the regions of Zarafshan river basin but agricultural production may suffer from negative impacts of climate trends in distant future. The results of this study is consistent with the findings of previous studies conducted in the case of Central Asian countries [11, 29].

5. Conclusions

This study reviewed the climate change trends through agricultural transition and analyzed the impact of weather variations on wheat yield in three administrative regions of Zarafshan river basin. Zarafshan river basin is one of origin place in Uzbekistan as of main supplier of gross agricultural products and agricultural development. Despite the favorable climate for agricultural purposes in the region, agricultural sector has been suffering due to frequent droughts and inefficient water use through the transition. Empirical analysis revealed that, annual temperature has positive influence on wheat yield in short run but wheat farmers may suffer in distant future from increased temperature on their production. The annual precipitation amount has positive relation with production. In terms of seasonality changes, increase in temperature was found to have significant negative impact in all seasons. While, precipitation has significant positive influence in all seasons except summer in the basin. Based on the findings this study, we recommend for the implementation of further researches considering adaptation behavior of agricultural producers and improvement of water management in Zarafshan River Basin.

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