REA Italian Review of Agricultural Economics ONLINE FIRST

Manuscript was received 22/01/2024
Revised manuscript was received 29/06/2024
Manuscript was accepted for publication 25/07/2024
Corresponding editor: Filiberto Altobelli

Research article

Perceptions towards Climate Change, Water Scarcity and Adaptation Strategies: Case of the Zerafshan River Basin in Uzbekistan

Sherzod Babakholov[1,*], Shavkat Hasanov[2]
[1] Department of Economics and Business, Samarkand Agro-innovations and Research University (SamARU), Uzbekistan
[2] Rector of Samarkand Agro-innovations and Research University (SamARU), Uzbekistan
*Corresponding author E-mail: Sherzod311377@gmail.com

Abstract

Adapting to climate change under different agro-ecologies of Central Asian countries still remains a matter of debate. The present study aimed to explore the perceptions and key factors influencing adaptation strategies through the stepwise appraisal framework in upstream zones of the Zerafshan River Basin in Uzbekistan. First, a Severity Index (SI) was calculated to evaluate the perceptions of farmers towards climate change and water scarcity. Then, determinants of adaptation practices were investigated using a binary Logistic regression model with comprehensive farm-level survey data collected from 307 farmers. The highest value of the SI coefficient was attained for the perception "Water resource is getting scarce", which implies that most farmers already have worries about the potential risk of water shortages although they have been operating with an adequate water supply. Education of household head, extension, and farmer's perceptions on climate change and water were found to be positive determinants but land size and membership in agro-clusters were found to be negatively influenced factors to climate adaptation strategies. Therefore, we suggest policy implications to consider the land size, cooperation of farmers with clusters, extension, and water management systems to increase the resilience of farmers against climate change at national level.

Keywords: Climate change, agriculture, water use, adaptation
JEL codes: Q12, Q25, Q54

Highlights:

- Climate change impacts are becoming worse with particular effects on yield losses and water distribution among agricultural producers even in upland areas of Central Asian countries.
- Farmers' perception on water shortages is higher than climate change impacts in the study region.
- Education of household head and extension were found to be positive but land size and membership in agro-clusters were found to be negatively influenced factors to climate adaptation strategies.

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record.

Please cite this article as:

Babakholov S., Hasanov S. (2024). Perceptions towards Climate Change, Water Scarcity and Adaptation Strategies: Case of the Zerafshan River Basin in Uzbekistan. *Italian Review of Agricultural Economics*, Online First
DOI: 10.36253/rea-15098

1. Introduction

Climate change and its adverse consequences have already become a basic strategic concern of the 21st century while posing challenges not only to agro-ecological but to socioeconomic stability of the world society (Liu *et al*., 2020; Gosling *et al*., 2016). According to Nautiyal *et al*. (2022) climate change is a change in the global atmosphere that is directly or indirectly related to human activity, which leads to the melting of glaciers, an increase in floods and landslides, a decrease in the flow of rivers, and an attack on ecosystems. When we got the recent declaration by scientists about climate change and its expected consequences, it was thought that this phenomenon was far away and would not affect humanity. However, today we fully feel all aspects of these changes in our lives. Agriculture is the most climate-sensitive sector, in which many of the adverse influences of climate extremes are likely to occur and its players suffer (Ali *et al*., 2017). Increases in temperature and erratic patterns of precipitations have been altering the water provision and production possibilities of world agricultural producers with particular effects on crop yield and income. Along with this, the level of climate influence also depends on the adaptive capacity of agricultural producers (Gbetibouo, 2009). World rural societies with poor access and limited adaptive capacities are predicted to suffer more in the near and distant future from the potential and actual impacts of climate-driven changes (Liu *et al*., 2020).

As global climate change continues on the earth, its negative impacts on agriculture and global food security are becoming more acute. Developing countries are more vulnerable to climate change due to the vast number of rural livelihoods, dependency on an agriculture-based economy, and lack of assets (IPCC, 2014; Ali *et al*., 2017). Furthermore, with their rapid progress in industrialization, developing countries were already challenged in terms of food security, water scarcity, land degradation, and increased demand for agricultural production through the exacerbated threats posed by climate change (Mwongera *et al*., 2017). In this regard, adaptation is increasingly urgent for developing nations like Central Asia, where the livelihood of a vast number of the population is still predominantly related to agriculture (IPCC, 2014; Siegfried *et al*., 2012; Gosling *et al*., 2016).

Central Asian countries are more climate-sensitive due to the high level of uncertainty regarding precipitation and increased warming trends over the past decades (Babakholov, 2021; Muratov *et al*., 2023). Global warming and regional precipitation patterns have increased the rate of evaporation, and droughts have become more severe, impacting agricultural production and water use (Huang *et al*., 2016; Liu *et al*., 2020). In addition, several studies predicted that drought frequencies are becoming more severe and this might pose more glacier melting and subsequently high levels of water shortages in Central Asia. Downstream dry regions of Central Asia and little summer precipitation have already faced water shortages in their agricultural production, whereas seasonal runoff maxima have also been observed in some rivers (Sorg *et al*., 2012). In turn, those climate threats have damaged the livelihood and revenues of rural societies of the downstream and arid countries like Uzbekistan, where irrigated agriculture is still predominant in the national economy (Siegfried *et al*., 2012; Karthe *et al*., 2015).

The irrigated agriculture of Uzbekistan mainly relies on water sources, of which more than 80% originates outside the borders. Amu Darya, Syr Darya, and Zerafshan rivers are the major water sources for Uzbekistan, while less than 10% of water originates domestically (World Bank Group, 2021). A large number of studies have concerned climate change, water issues and agricultural production in the case of Central Asia and different geographic zones of Uzbekistan. The irrigation demand in Uzbekistan is predicted to increase by 16% by 2080, this would increase competition for water and impose risks on agricultural production with a potential reduction in crop yields (World Bank, 2018b). Additionally, Uzbekistan suffers from land degradation by secondary soil salinization in response to suboptimal irrigation/drainage management and shallow, saline groundwater levels (Sommer *et al*., 2013). Bobojonov *et al*. (2016) discussed the income and irrigation water use efficiency of agricultural producers under the climate change context in the western part of Uzbekistan. The results show that farmers' income could fall by 25% as temperature increases by 3.2 ^{0}C and a 15% decline in irrigation, while the share of revenue loss of farmers operating in downstream areas is even greater. Considering water use efficiency, 65.2% of applied water was used efficiently, and about 35% of total water was lost during irrigation of the crops. Babakholov *et al*. (2022) analysed the interactive effect of climate change and irrigation on farm output. Their findings indicate that farmers with sufficient water and improved irrigation techniques are more resilient and profitable, although a temperature increase is witnessed. As per the findings of Salokhiddinov *et al*. (2020) low-income levels, high dependency on irrigation, lack of technologies, adaptation measures, low yields, and land degradation were found to be the main vulnerabilities of rural inhabitants.

Meanwhile, studies by Reyer *et al*. (2017) and Sutton *et al*. (2013) indicated the likelihood of a 20-50% yield loss under the projected average temperature rise up to 2 ^{0}C by 2050 in Uzbekistan if sufficient adaptation measures have not been implemented. Despite the recent and current ongoing adaptation measures taken at regional and national levels in Central Asia, there are still noticeable gaps such as limited knowledge, insufficient technologies, poor infrastructure, climate-oriented techniques which pose barriers on implementing and underlying the accurate solutions for adaptation (Laws, Balance, 2016; Smit, Skinner, 2002). Furthermore, a large number of studies have already looked at reducing the risk and vulnerability level, while analysing the diverse frameworks of climate adaptation at national and international levels (Aleksandrova *et al*., 2016; Arnell *et al*., 2016; Garschagen, Romero-Lankao, 2015; Schlaepfer *et al*., 2017; Liu *et al*., 2020). Notwithstanding this, very few studies have considered the farmers' perceptions toward climate change and water scarcity jointly with adaptation strategies under the condition of sufficient water provision at basin scale.

The present study proposed to analyse the perceptions and determinants of adaptation practices in the case of farmers who fully use irrigation operating in upstream zones of the Zerafshan River Basin in Uzbekistan. The contribution of this research is threefold for the global context of climate change: first, it clarifies the perceptions of agricultural producers on actual and potential impacts of climate-driven changes and water resources in the case of farmers operating with sufficient water supply. Second, it identifies the main factors that influence farmers' decisions to implement adaptation practices. Finally, the findings enable us to draw the most important policy implications and regulatory frameworks that are needed to support agricultural water use and adaptation strategies in the study region.

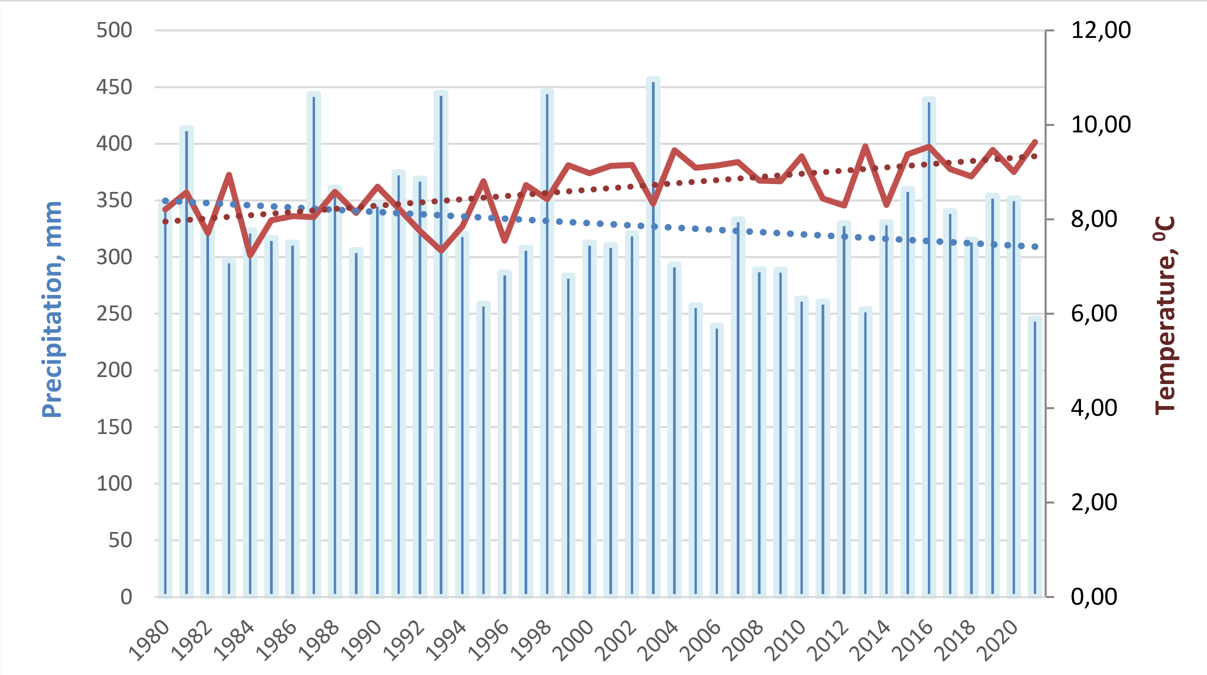
2. Climate change and water issues in Central Asia

Central Asia comprises five former Soviet Union countries, namely Kazakhstan, Turkmenistan, Kyrgyzstan, Tajikistan and Uzbekistan, with about 4 million km^2 of total area and an arid and semi-arid climate with dry ecosystems and rainless environments (Lioubimtseva, Henebry, 2009; Zhang *et al*., 2019). Only 20% of land in Central Asia is suitable for farming purposes and the rest are temperate deserts (Zhang *et al.*, 2017). Agricultural producers in Central Asia are vulnerable and suffer from climate threats due to several factors including heterogeneous geography, increased temperature and altered rainfalls, aridity and droughts, water scarcity, increased demand for agricultural production, and low-level investment and adaptive capacities (Seddon *et al*., 2016; Zhang *et al*., 2019).

The climate of Central Asia is semi-arid and arid continental, with summers being hot and dry and winters being cold mostly in the northern areas (Djanibekov *et al*., 2015). The climate of the region has been changing at a greater rate than global averages since the 1950s

(Mirzabaev, 2013). There are big uncertainties in the projections of potential impacts of climate change on the region, notably in terms of precipitation and irrigation water runoff dynamics. The annual mean temperature of the region ranges from 1.6 to 15 ^{0}C and receives on average about 250-300 mm precipitation annually (World Bank, 2018a). Temperature increase has been observed since 1970 and both summer and winter temperatures in Central Asia are predicted to rise up to +4.4 ^{0}C and beyond by the 2050s (IPCC, 2014). Numerous past studies on the assessment of climate-driven changes indicated different results based on the data and geographical conditions of the region. Findings explored by Lioubimtseva and Henebry (2009) show that the increase in warming on average is projected to reach +3 ^{0}C and will even exceed +5 ^{0}C in some arid and temperate regions of Central Asia by 2071-2100.

Figure 1. Dynamics of annual mean temperature and precipitation in Central Asia, 1980-2020



Source: Authors' own compilation based on data from the gridded time-series (TS) Version 4.01 (CRU, 2021) and the World Bank (2021b).

The dynamics of changes in annual mean temperature and precipitation amount in Central Asia for the period of 1980-2020 are illustrated in Figure 1. As we are able to see and judge from the above figure, there was a feasible increase in mean annual temperature in the region from the 1990s, while it was about +8 ^{0}C at the beginning of 1980s and reached almost +10 ^{0}C by 2020. There has been an observed decline in annual precipitation in the region over the past decades. Annual precipitation was about 350 mm in the last decades of the past century but it fell to 300 mm in 2020.

Water resources and water management are of central importance at the present time in Central Asia, where a large part of the population still relies on heavily irrigated agriculture and animal husbandry (Xenarios *et al*., 2019). Climate change impacts are believed to be strong and adverse not only to agricultural production and rural livelihoods but also to hydrological cycles and water availability in the downstream regions of Central Asia (Hill *et al*., 2017). Water levels of the Amu Darya and Syr Darya, which are the main sources of irrigated agriculture in the region have decreased by 20%-30% due to climate change impacts observed in past decades (Lioubimtseva, Henebry, 2009; Ososkova *et al*., 2000). The water sources that Central Asian societies use for domestic and agricultural purposes mainly depend on glacier meltwater (Pritchard, 2019). The tendency of glacier melt from Tien Shan mountains has intensified under the climate change context since 1970, while the precipitation and water amount from other sources have reduced (Narama *et al*., 2010). The glacier melting without snow cover in mountain regions of Central Asia has been accelerated via the increased annual surface mean temperature and the reserves for river basins have lost up to 30%-35% over the past five decades (Karimov *et al*., 2019; Harris *et al*., 2014; Zhang *et al*., 2019). Along with this, as per findings of studies by Hagg *et al*. (2013) and Punkari *et al*. (2014), CMIP3 model results projected a

22%-35% additional decline in water supply from Amu Darya and Syr Darya into downstream regions under the temperature rise dynamics of between 2.2^{0}C and 3.1^{0}C by the 2050s. More importantly, the increase in air temperature was slight in summers but a remarkable rise in warming was observed for the month of September over the past decades in Central Asia. This implies a prolonged glacier melting period with the potential risk of high-level water shortages together with ecological and political instability in the region (Bolch, Marchenko, 2006). Due to a lack of cross-border water management agreement among Central Asian countries, water use for agricultural irrigation in downstream countries like Uzbekistan largely remains dependent on the polices of upstream republics, whereas shortages are worsening with the increased demand for water (Aleksandrova *et al*., 2016).

By considering the above-highlighted issues related to climate change and water scarcity, adaptation measures such as policy responses at state level are vital for the region. A large number of studies show that climate impacts can be coped with through the implementation of various adaptation measures, although climate extremes are uncontrolled and detrimental to agriculture (Mendelsohn, 2008; Smit, Skinner, 2002). Regarding climate change adaptation, the governments of Central Asian countries have already shown a high sense of urgency in coping with climate change and have been actively participating in international projects co-funded by donors (Xenarios *et al*., 2019). On the political and economic side, a number of reforms and development projects have recently been included in national laws, strategies and management programmes of Central Asian countries, which mainly focus on climate adaptation and resilience activities. Despite several national climate action plans integrated into environmental policies, there are currently no national climate action plans in Uzbekistan. In the context of climate adaptation, improving irrigation and water use efficiency, developing a water monitoring system, and forest management policies are the strategies that are currently concerned at the state level in Uzbekistan. Notwithstanding this, a poor level of infrastructure in rural areas, worsened arid conditions, water scarcity, lack of input access, as well as the heterogeneous knowledge gap on environmental and socio-economic consequences of climate extremes are still determining the vulnerability of rural actors in the country (Xenarios *et al*., 2019). This in turn intensifies the necessity for research concerned with adaptation measures against future climate threats and boosting the resilience of agricultural producers in the country.

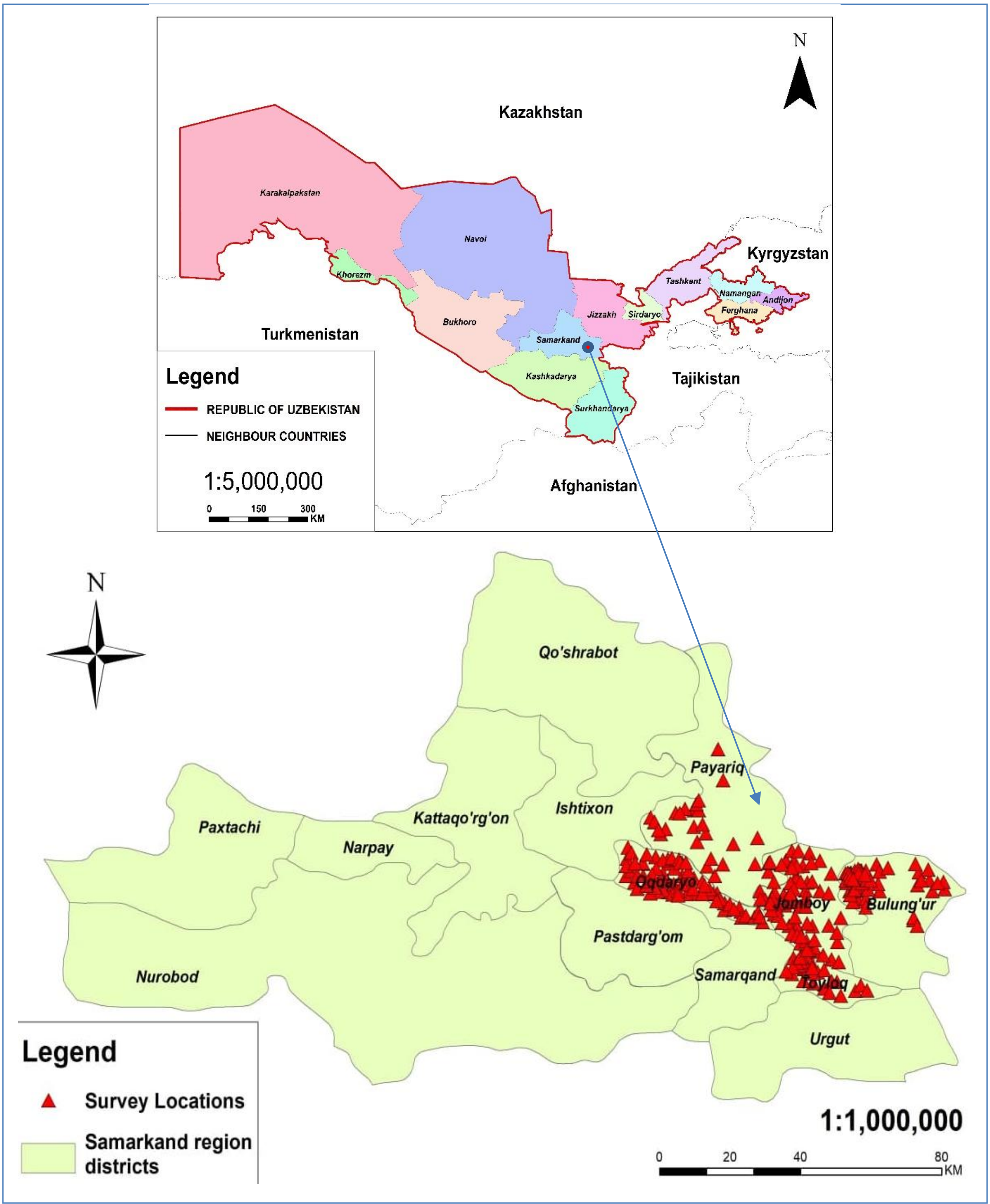
3. Materials and methods

3.1. Study site

An empirical analysis of the study was conducted in the case of farms operating with sufficient water supply in upland zones of the Zerafshan River Basin. Based on capacity and territory, the Zerafshan River Basin is one of the strategic places for Uzbekistan, which comprises two big administrative provinces, namely Samarkand and Navoi, with well-developed irrigated agriculture and industry (Khujanazarov *et al*., 2012; Babakholov *et al*., 2022).

Samarkand region lies in the main upland part of the Zerafshan River Basin. Located about 700 metres above sea level, the Samarkand region has a dry continental climate with hot summers and partly cold winters (Sommer *et al*., 2013; UzHydro-Met, 2018). The area of the region consists of 1677.3 thousand hectares, of which about 430 thousand hectares (irrigated and rain-fed) are agricultural cropland (SCRUz, 2022). Geographically, the region is surrounded by mountains and has suitable weather conditions for agricultural purposes and is the second main supplier of gross agricultural output of the country (Babakholov *et al*., 2018). A total of 14 districts are included in the administration of the Samarkand region, of which 4 districts are located in the upper tail of the basin and produce mostly cash crops, 5 districts are in the mid-tail and grow mostly cotton and wheat, 3 districts are in the lower tail and wheat, cotton as well as grapes are common crops for those zones. Rain-fed agriculture is common in only two districts, which are in the south and north-western parts of the region, and specialized almost entirely in livestock breeding. The map of the study region and the location of surveyed farmers is shown in Figure 2.

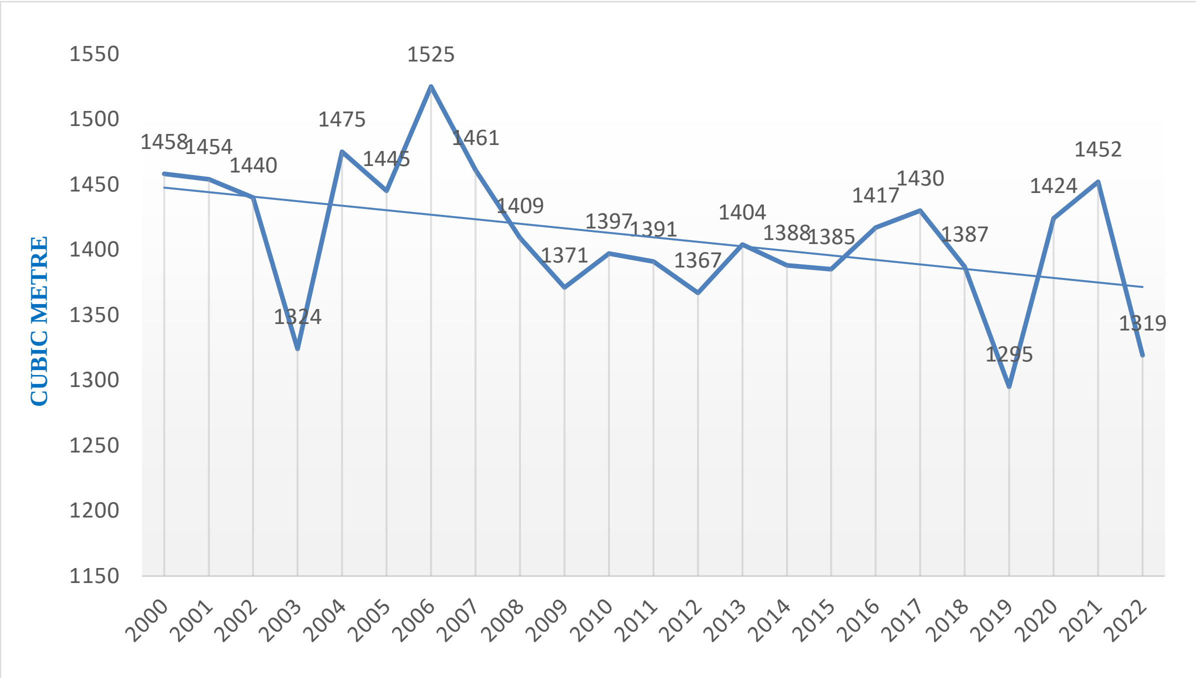
Figure 2. Map of the study region and the location of surveyed farmers



Source: Authors' completion using ArcGIS software 10.3

The Zerafshan River originates from the neighbouring republic of Tajikistan and flows through Uzbekistan with a total length of 780 km (Khujanazarov *et al*., 2012). More than ¼ of the total population of Uzbekistan lives in the territory of the basin and their agricultural livelihood is entirely dependent on water sources from the Zerafshan River (Kulmatov *et al*., 2013). Due to irrational water use, poor drainage and water management systems as well as exacerbated climate threats, the irrigation capacity of agricultural producers is worsening even in upstream areas of Zerafshan River Basin. A gradual increase in climatic water deficit per square metre has also been observed in the territory of the Zerafshan River Basin within the past decades (Figure 3). Based on statistics of the World Bank (2022), about 485 m^3 climatic water deficit per square metre was observed in the basin in 2022 compared to 2000. This intensifies the necessity and urgency of adaptation measures towards increasing the farmers' climate resilience, water management, and sustainable agricultural production in the region.

Figure 3. Dynamics of climatic water deficit per square metre in Zerafshan River Basin, 2000-2022



Source: Author's completion based on data obtained from World Bank, 2022.

3.2. Data and variable description

Farm-level cross-sectional data was utilized for an empirical analysis of the study. The questionnaire was first designed following the objectives of the study and international standards. A total of 307 large-scale farmers who use irrigation were randomly selected and interviewed face-to-face through the structured questionnaire based on their outcomes in 2021. The survey was conducted in five upstream districts of the Samarkand region during the months of July and August 2022. Surveyed study districts are considered as the main producers of cash crops in the agricultural structure of the Samarkand region with sufficient water provision and fertile soil. The number of samples from each district represents roughly 10 percent of total farmers who mostly grow cash crops such as wheat, potatoes and vegetables. The summary statistics of the farm level dataset are illustrated in Table 1. The dataset includes the set of farm demographic, socio-economic, farm production, climate and water-related variables.

The descriptive statistics table gives detailed information about the response and explanatory variables obtained through the interviews. Starting from the dependent variable, a set of different adaptation strategies (water management, nutrition management, adjusting sowing time, drought and disease tolerant varieties, switching to new crop, crop rotation, and tree planting) encoded as a dummy, while 1 if the farmers have applied any of adaptation measures against climate change or 0 otherwise. A total of 14 independent variables were considered as main determinants that could encourage farmers to implement any of the adaptation activities, while those variables were also used globally in previous studies by Amfo and Ali, (2020), Makate *et al*. (2019), Ali *et al*. (2017), Abid *et al*. (2015), Bryan *et al*. (2013) and Deressa *et al*. (2009). The age of surveyed farmers is 45 years old on average and they have 12 years of farming experience. The land size of the farmers became bigger after the land optimization reforms were made in the country in 2019. Surveyed farmers own 39.1 hectares of land in 5.5 plots on average in study districts. It should be noted that farmers with financial and institutional assets are more eager and able to adopt and introduce innovations and new technologies to their farming activities.

Table 1. Summary statistics of dependent and independent variables

Variables	Description	Mean	Std.Dev
Dependent variable			
Adaptation strategies	1 if the farmer has applied any of climate adaptation practices, 0 otherwise	0.60	0.4901
Independent variables			
Age	Age of the farmer in years	45	11.26
Education	Dummy, 1 if the farmer has higher education, 0 secondary or other	1.4	0.4902
Experience	Farming experience of farmer in years	12	6.3670
Off-farm income	Dummy, 1 if the farmer has another income source, 0 otherwise	0.17	0.3813
Livestock	Number of livestock owned by the farmer	9	7.3575
Land size	Farmland owned, ha	39.1	28.289
Credit	Dummy, 1 if the farmer has access to credit, 0 otherwise	0.12	0.3261
Extension	Dummy, 1 if the farmer has access to extension, 0 otherwise	0.34	0.4272
Market access	Dummy, 1 if the farmer has market access, 0 otherwise	0.72	0.4465
Weather information	Dummy, 1 if the farmer follows weather information, 0 otherwise	0.73	0.7328
Membership	Dummy, 1 if the farmer is a member of the cluster, 0 otherwise	0.38	0.4864
Climate change	Dummy, 1 if the farmer has experienced climate change, 0 otherwise	0.63	0.4812
Temperature increase	Dummy, 1 if the farmer reported temperature increase, 0 otherwise	0.44	0.4979
Water scarcity	Dummy, 1 if the farmer reported water shortages, 0 otherwise	0.33	0.4741
Farm outcomes			
Wheat yield	Harvested wheat yield in kg/ha	4181	721.63

Potato yield	Harvested potato yield in kg/ha	26000	6599.8
Tomato yield	Harvested tomato yield in kg/ha	30716	11204
Legumes yield	Harvested legume yield in kg/ha	2220	1624.8

Source: Authors' calculation based on survey data.

Among the surveyed farmers 25.4% have higher education and 74.5% are operating at the secondary or primary school level. In addition, 17.5% of farmers have additional income from non-agricultural sources, while more than 80% of farmers' livelihood is directly related to agriculture. Those factors are important to adopting innovations and new technologies and have also been applied in a wide range of previous studies (Amfo, Ali, 2020; Ali *et al.*, 2017; Alemayehu, Bewket, 2017). Sampled farmers own about 9 heads of livestock units on average. The rest of the variables contain more about environmental and institutional factors.

3.3. Empirical framework (Severity Index and Model specification)

There are different and broadly used methods in the world literature for assessing perception accuracy and the factors that have an influence on choice selection. In particular, farmers implement different adaptation practices based on climate challenges and their own resources and assets. In this study, we applied a stepwise empirical framework to meet the research objectives. Farmers' subjective perceptions of climate change and water issues were calculated using the mathematical technique, which is the Severity Index (SI). The index and its analytical criteria were introduced by Majid *et al.* (1997) and calculated using the following formula:

$$SI = \sum_{i=0}^{4} p_i \, q_i / n \sum_{i=0}^{4} qi \quad (1)$$

Where SI – is the coefficient of the calculated Severity Index (SI);
(p_0, p_1, p_2, p_3 and p_ (4)) are the response frequencies of the farmers (perceptions) with respect to the 5-point Likert Scale (q_0=0, q_1=1, q_2=2, q_3=3, q_4=4);
n – is the total number of observations against a 5-point Likert Scale.
Following Majid *et al.* (1997) and Ferdushi *et al.* (2019), Severity Indexes' analytical criteria were specified as follows:
q_0 = Strongly disagree, 0.00 ≤ SI ≤ 12.5;
q_1 = Disagree, 12.6 ≤ SI ≤ 37.5;
q_2 = Moderate agree, 37.6 ≤ SI ≤ 62.5;
q_3 = Agree, 62.6 ≤ SI ≤ 87.5;
q_4 = Strongly agree, 87.6 ≤ SI ≤ 100.

According to the above criteria, farmers' perception accuracy on climate change and water shortages has been analysed. Accordingly, climate change hasn't yet had a serious effect and there is no problem with water provision if the calculated value of the SI coefficient lies between 0.00 – 12.5 and 12.6 – 37.5. Meanwhile, farmers moderately agree with climate change influences and water shortages through the coefficients of 37.6 and 62.5. Moreover, climate change impacts and water problems were observed among agricultural producers if the attained value of SI coefficients were above 62.6 and 100 respectively.

The effect of predictor variables on adaptation was investigated in the second stage of analysis. After the perceptions on climate change and water scarcity, farmers were asked whether or not they implemented any adaptation strategies in their farming activities, with possible binary answers of yes or no. When the outcome variable is in binary classification, Logit and Probit models are most common in statistical analysis. These models are capable of predicting the probability of something occurring in the form of a binary outcome and are also better for controlling deterministic and heteroskedastic problems than linear probability models with maximum likelihood technique (Dougherty, 2011). Although both models are similar, they use different functional approaches, which are logistic and cumulative normal distribution to link the relationship between explanatory and outcome variables. Since the Logit model is more robust to outliers with its logistic function, we considered and applied the Logit model to our empirical analysis.

In general, Logit models have two types of forms, which are multinomial and binary logits. In our study, the binary form of the logistic regression model was used and specified as follows:

$$Logit\ (P) = \log\left(\frac{P}{1-P}\right) = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \qquad (2)$$

Where, the binary response has two possible outcomes Y, which 1 = farmers adopted any of practices, and 0 = otherwise;
α_0 – is the intercept;
X_n – is the set of explanatory variables, which are the factors that affect adaptation;
β_n – is the model parameters estimated through the maximum likelihood method;
P/(1-p) – denotes the odds ratio while implying the ratio of the probability of the factors that farmers have either successfully adopted or not adopted any of the adaptation strategies against climate challenges. From the statistical point of view, the influence of the predictor variables on adaptation is positive and significant if the value of the odds ratio is greater than one. In contrast, explanatory variables do not take a positive relation if the value of the odds ratio is less than one (Ferdushi *et al*., 2019; Alemayehu, Bewket, 2017).

4. Results

4.1. Farmers' Perceptions (Severity Index)

Perception accuracy is one of the important indicators before drawing policy recommendations and related practical implementations. A set of climate change and water-related items were elaborated and asked to evaluate the perceptions of the farmers with respect to climate and water issues. The purpose of calculating the index is to better understand the perceptions of farmers on actual and potential impacts of climate change and water scarcities before analysing the determinants of adaptation practices they have currently been adopting on their farming performances. The coefficient of the Severity Index (SI) was calculated using the formula (1) explained in previous studies by Majid *et al*. (1997) and Ferdushi *et al*. (2019). The calculation procedure is implemented as follows:

Table 2. Calculation procedure of the Severity Index (SI)

a)	*SI* =	$(0\times0+13\times1+7\times2+176\times3+111\times4)/(0+13+7+176+111)=3.25;$	SI $=\frac{3.25}{4}\times100=$ 81.35;
b)	*SI* =	$(7\times0+40\times1+20\times2+163\times3+77\times4)/(7+40+20+163+77)=2.86;$	SI $=\frac{2.86}{4}\times100=$ 71.25;
c)	*SI* =	$(12\times0+79\times1+34\times2+130\times3+52\times4)/(12+79+34+130+52)=2.42;$	SI $=\frac{2.42}{4}\times100=$ 60.5;
d)	*SI* =	$(2\times0+16\times1+24\times2+199\times3+66\times4)/(2+16+24+199+66)=3.01;$	SI $=\frac{3.01}{4}\times100=$ 75.25;
e)	*SI* =	$(30\times0+86\times1+32\times2+154\times3+1\times4)/(30+86+32+154+1)=2.01;$	SI $=\frac{2.01}{4}\times100=$ 50.1;
f)	*SI* =	$(0\times0+50\times1+28\times2+165\times3+64\times4)/(0+50+28+165+64)=2.81;$	SI $=\frac{2.81}{4}\times100=$ 70.25;
j)	*SI* =	$(0\times0+48\times1+16\times2+134\times3+109\times4)/(0+48+16+134+109)=2.99;$	SI $=\frac{2.99}{4}\times100=$ 74.75

Source: Authors' calculation based on survey data and the Formula (1).

Where the sum of response frequencies of the surveyed farmers on each item with respect to climate change and water issues is multiplied with the order of Likert Scale coefficients and divided by the total number of observations respectively. Then derived coefficients were divided against 5 point Likert Scale order and Severity Index (SI) coefficients obtained for each perception related with climate change and water issues in the region. The results of the Severity Index (SI) are shown in Table 3.

Table 3. Farmers' perceptions toward climate change and water issues

Description of the selected frames		**SD (0)**	**DA (1)**	**MA (2)**	**A (3)**	**SA (4)**	**Severity Index (%)**
Water resources are becoming scarce	NRS	0	13	7	176	111	81.3
	PRS	0	4.2	2.3	57.3	36.2	
Climate change has already affected agriculture and water resources of Uzbekistan	NRS	7	40	20	163	77	71.2
	PRS	2.3	13	6.5	59.1	25.1	
Climate change is a serious problem	NRS	12	79	34	130	52	60.5
	PRS	3.9	25.7	11.1	42.3	16.9	

Climate change effects my farm production	NRS	2	16	24	199	66	75.2
	PRS	0.7	5.2	7.8	32.2	54.1	
Precipitation is decreasing	NRS	30	86	32	154	1	50.1
	PRS	9.8	28	10.4	50.2	1	
Temperature is increasing	NRS	0	50	28	165	64	70.2
	PRS	0	16.3	9.1	53.7	20.8	
Adaptation is necessary for all of us	NRS	0	48	16	134	109	74.7
	PRS	0	15.6	5.2	43.6	35.5	

Note: NRS – number of respondents; PRS – percentage of respondents; SD – strongly disagree; DA – disagree; MA – moderate agree; A – agree and SA – strongly agree;

N – 307 farmers.

Source: Authors' calculation based on survey data.

Attained Severity Index (SI) values range from 50.1% to 81.3%. The highest value of SI was attained for the perception "Water resources are becoming scarce". The next highest number of followers was attained for the perceptions "Climate change effects my farm production" and "Adaptation is necessary for all of us" with values of 75.2% and 74.7% respectively. Likewise, the perceptions "Climate change has already affected agriculture and water resources of Uzbekistan" and "Temperature is increasing" corresponding to 71.2% and 70.2% were calculated. The lowest values of SI were attained for the perceptions "Climate change is a serious problem" and "Precipitation is decreasing" corresponding to 60.5% and 50.1% respectively. The above attained Severity Index (SI) values indicate that farmers are sufficiently aware and agree with the overall and particular impacts of climate change events on their farming activities. Importantly, most farmers perceived the water shortages as a more problematic issue than other threats although they have been endowed with sufficient water in upstream zones of the Zerafshan River Basin. Furthermore, by taking into account climate change and the potential risk of water shortages, farmers considered the necessity for climate change adaptation practices for sustainable agricultural production and livelihood.

4.2. Determinants of farmers' adaptation practices

A set of explanatory variables were regressed upon farm adaptation practices. Selected factors were incorporated into the regression analysis based on their correlation statuses and economic theory. Detailed results of the Logistic regression model are given in Table 4. In this study, the dependent variable is the presence of farmers' adaptation strategies against climate challenges.

Table 4. Determinants of farmers' climate adaptation practices (results of Logistic model)

Variables	Measurement unit	Odds Ratio
Age	years	- 0.97 (0.014)
Education	dummy	1.48 (0.538)*
Experience	years	1.04 (0.027)*
Off-farm income	dummy	- 0.47 (0.199)*
Livestock	number of heads	1.01 (0.018)
Land size	hectare	- 0.98 (0.004)***
Credit	dummy	1.81 (0.802)
Extension	dummy	2.02(0.573)**
Market access	dummy	1.32(0.377)
Weather information	dummy	1.05 (0.301)
Membership	dummy	- 0.48 (0.132)**
Climate change	dummy	1.56 (0.469)*
Temperature increase	dummy	1.06 (0.272)
Water scarcity	dummy	1.35 (0.364)

Note: *, **, and *** denote the significance of the coefficients at 0.1, 0.05, and 0.01 level.
Source: Authors' calculation based on survey data.

According to model results, farm socioeconomic variables such as age group of the farmer were found to have a negative but not significant relation with climate adaptation practices. It implies that younger farmers are more eager and faster than elders in terms of technological changes and adopting innovations for their better performance. Meanwhile, age and experience are interrelated factors that may have cumulative impacts on adaptation. In our results, farming experience was found to be a positively related determinant. The education level of the farmers also has positive and significant signs for adaptation strategies, while farmers with better education are more capable of adopting adaptation practices. In general, farmers with more assets are more successful in their operations, whereas additional income sources better encourage them to find solutions against challenges. In another case, farmers with a high level off-farm income source may quit agricultural activities. In our study findings present the negative relation between off-farm income and the positive relation of livestock ownership with adaptation practices. Agricultural land is a major livelihood asset and wealth indicator for the farmers. In this study, the sign of land size was found to have a negative correlation with adaptation practices.

Institutional and market accessibility factors are important for coping with and mitigating climate threats. The investigated values of farmers' access to credit, market, and whether information is positively correlated with adaptation strategies. Agricultural producers with good access capacity are more capable of managing climate-related risks. In particular, the coefficient of extension was found to be highly significant and positive to climate adaptation strategies. Surprisingly, a negative correlation was found between membership of agricultural clusters and adaptation strategies. This may be because of the new system and inclusive transformation in the agricultural sector of the country. Moreover, farmers' perceptions of overall climate change, temperature increase and water scarcity were found to have a positive and significant relation with adaptation, while as climate extremes increase farmers intensify their efforts in order to adopt best practices.

5. Discussion

Developing countries are more vulnerable and less resilient to the adverse consequences of climate change due to poor market and institutional accessibility and limited adaptive capacity. As per results of previous studies by Babakholov *et al*. (2022), Radchenko *et al*. (2017) and Bobojonov *et al*. (2016) climate change has already become acute to the agriculture of Uzbekistan, with particular threats to agricultural production, water resources, food security and rural income. Continued droughts and water shortages accelerated climate challenges even in irrigated areas of the country and this intensified the urgency and necessity of adaptation at local and national levels. In this regard, the present study attempted to investigate the farmers' perceptions on climate change and water shortages together with the main determinants of adaptation strategies in the case of farmers operating with sufficient water supply in the Zerafshan River Basin in Uzbekistan. The empirical analysis was implemented using farm-level survey data and a climate-oriented framework by corresponding previous literature (Ferdushi *et al*., 2019; Delaporte *et al.*. 2018; Alemayehu *et al.*. 2017). At the primary stage of the analysis, the Severity Index (SI) was calculated using the data which included a set of climate and water-related items asked to farmers in order to measure their perception accuracy on observed climate events and water issues. The initial findings of this study on farmers' perception show that farmers in the study region are sufficiently aware of climate change consequences and confirmed the adverse impacts of climate threats on their production and water usage as well. Interestingly, farmers' perception on water shortages was found to be higher than the perception on climate extremes, while farmers have more worries about the potential risk of water shortages in the near future although they have been operating with sufficient water provision. As already mentioned by farmers involved in agricultural production the evidence of temperature rises and rainfall drop has occurred in their areas. Overall, farmers take both climate change and water issues as problematic concerns and give most consideration to the necessity for adaptation practices because these problems are directly and indirectly affecting their income loss and livelihoods respectively.

Meanwhile, this study explored the association between the farm's socio-economic, and institutional characteristics and climate adaptation strategies in the next step of analysis. Although the majority of findings of this study corroborate the results of other studies conducted globally, some results were found to be contrary and specifically study region-related. Age and experience are interrelated factors that may have interactive positive impacts on outcomes (Mulwa *et al*., 2017). In this study experienced farmers were found to have more positive attitudes to take adaptation measures. Notwithstanding, the age of the farmer was found to be a negatively associated factor to adaptation and thus corresponds with the findings of recent studies (Yeo *et al*., 2020; Ali *et al*., 2017; Tesfaye *et al*., 2016). While younger farmers are more likely to be innovative and active, the older generation is found to be negatively affecting the adaptation rate. This is because old farmers prefer to stick with their existing farming practices which are already not sufficient to overcome challenges. As confirmed in other studies across the continent Rahut *et al*. (2017), Alemayehu *et al*. (2017), Abid *et al*. (2015) and Bryan *et al*. (2013), the sign of farmers' education was found to be positive and significant for adaptation strategies, implying that educated farmers with good theoretical background could be sufficiently aware of climate change consequences and be more active and precise in adopting the best strategies against climate threats. Agricultural producers often rely on non-agricultural profits or assets to improve their outcomes or to combat challenges. In our study, there is a negative correlation between off-farm income and the positive correlation of livestock with adaptation. Theoretically, wealthy farmers with financial ability are more like to invest in innovations and technologies. At the same time having off-farm income may have either a positive or negative influence on farmers' decisions, while with good non-agricultural income, farmers may quit farming activities or be less motivated, especially under the condition of climate extremes and water shortages.

Farm institutional and market accessibility are also paramount for better outcomes. Our findings indicated the positive association of credit, market, and weather information access in adaptation strategies although the coefficients were not statistically significant. Farmers with good market and credit access can improve their adaptive capacity, which enables them to implement climate adaptation measures on time in the study region. The results are consistent with previous research (Yeo *et al*., 2020; Adimassu *et al*., 2016; Abid *et al*., 2015; Yegbemey *et al*., 2013). Along with this, the positive and significant relation of extension access with farm adaptation practices was explored. Extension access could enhance farmers' ability, whereas farmers with good extension are more likely to have accurate information on climate-driven threats and be precise in coping with climate risk management (Ali *et al*., 2017; Deressa *et al*., 2009). Agricultural land is the main asset of the farmers, which enables them to survive and better develop their livelihoods. Owning a large amount of arable land implies more yield and more income respectively. On the other hand, it may pose some challenges in terms of management issues, as sampled farmers reported during the interviews. Even though the majority of previous studies Ferdushi *et al*. (2019), Ali *et al*. (2017), and Rahut *et al*. (2017) found a positive association between land size and adaptation, a negative-significant association of land size was found in the study area. In fact, private farmers own not less than 20 hectares based on their cropping pattern in Uzbekistan, particularly after the land optimization reform in 2019. This implies that the current amount of land given to farmers may pose managerial challenges with respect to climate adaptation practices in the study area.

Membership of the farming highlights the affiliation of farmers in any type of agriculture related communities, such as water users' association (WUA), farmers group (FG), and cooperatives, which generally also have a positive relation with agricultural output and adaptation strategies (Yeo *et al*., 2020; Piya *et al*., 2013). In this study membership denotes the farmers' affiliation in agro-clusters, which have recently been established in the country. Unlike the findings of other studies, the negative association of membership in adaptation practices is found in our study. As farmers reported, this may be due to the lack of mutual understanding and poor level of cooperation between the clusters and agricultural producers. Moreover, farmer's perceptions on climate change, temperature increase and water scarcity were found to have positively associated factors in adaptation practices. Similar findings were highlighted by the results of previous studies by Yeo *et al*. (2020) and Alemayehu *et al*. (2017). Overall, when agricultural producers perceive changes in climate patterns and face water shortages their willingness to adopt the best adaptation strategies would increase.

6. Conclusion

Climate change and its adverse consequences have already intensified the urgency of adaptation even in the irrigated zones of Central Asia. Climate change and water issues were reviewed and perceptions towards climate change and water shortages, together with determinants of adaptation practices, were investigated in the case of farmers operating in the upstream zones of Zerafshan River Basin in Uzbekistan. Farm-level survey data was collected through 307 interviews from 5 districts of the Samarkand region, which is located in the main body of the basin. In the first step, farmers' perceptions on climate change and water were measured using the Severity Index (SI) framework. The results of the index presented some interesting facts in the context of the study area, in which farmers perceive water issues as more problematic to their livelihood than climate extremes, although they have been endowed with sufficient water amount at present.

The effect of dozens of factors on the adaptive capacity of farmers and the influence of those factors may differ based on the context of the study region. Logistic regression was applied in order to investigate the main determinants of adaptation strategies. In line with other studies conducted globally, findings revealed some novel facts for the study region. Accordingly, education of household heads, extension, and farmers' perceptions on climate change and water were found to be positive determinants, but land size and membership in agro-clusters were found to negatively influence climate adaptation strategies. Based on the findings of this study, policy implications should concern the following aspects with respect to future climate extremes and water issues: i) land policy and cooperation between clusters and farmers should be strengthened; ii) awareness of agricultural producers on climate change and water issues needs to be increased; and iv) state policy should further concern extension and water management systems to increase the resilience of farmers against future climate challenges.

Despite the interesting findings that have been explored in the context of Central Asia, climate change adaptation processes still remain a matter of debate. Our study also has potential limitations due to limited data access and coverage issues. The estimations in the model are based on survey data and sampled farmers represent just one region. Therefore, we suggest further studies to make estimations with a broader dataset such as panel data, which enables better policies to be drawn in the context of climate adaptation.

Acknowledgements and Funding

First of all, we are thankful to anonymous editors for their time and efforts in order to improve the quality of the paper. The first author also thanks to Dr. Ihtiyor Bobojonov for his valuable comments and suggestions on the earlier version of the manuscript. The authors gratefully acknowledge the support of survey team works at Samarkand Agro-innovations and research university. Funding for this research made by the authors.

Author Contributions

Sherzod Babakholov: Conceptualization, Methodology, Software, Data curation, Writing-Original draft version. Shavkat Hasanov: Supervision, Validation, Writing- Reviewing and Editing.

Declaration of Competing Interest

The authors declare no conflict of interest in this manuscript.

Data Availability

Data will be made available by the corresponding author upon request.

References

Abid M., Scheffran J., Schneider U.A., Ashfaq M. (2015). Farmers' perceptions of and adaptation strategies to climate change and their determinants: The case of Punjab province, Pakistan. *Earth System Dynamics*, 6(1): 225-243. DOI: https://doi.org/10.5194/esd-6-225-2015.

Adimassu Z., Langan S., Johnston R. (2016). Understanding determinants of farmers' investments in sustainable land management practices in Ethiopia: review and synthesis. *Environment, Development and Sustainability*, 18(4): 1005-1023. DOI: https://doi.org/10.1007/s10668-015-9683-5.

Aleksandrova M., Gain A.K., Giupponi C. (2016). Assessing agricultural systems vulnerability to climate change to inform adaptation planning: an application in Khorezm, Uzbekistan. *Mitigation and Adaptation Strategies for Global Change*, 21(8): 1263-1287. DOI: https://doi.org/10.1007/s11027-015-9655-y.

Alemayehu A., Bewket W. (2017a). Determinants of smallholder farmers' choice of coping and adaptation strategies to climate change and variability in the central highlands of Ethiopia. *Environmental Development*, 24: 77-85. DOI: https://doi.org/10.1016/j.envdev.2017.06.006.

Alemayehu A., Bewket W. (2017b). Smallholder farmers’ coping and adaptation strategies to climate change and variability in the central highlands of Ethiopia. *Local Environment*, 22(7): 825-839. DOI: https://doi.org/10.1080/13549839.2017.1290058.

Ali A., Erenstein O. (2017). Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Climate Risk Management*, 16: 183-194. DOI: https://doi.org/10.1016/j.crm.2016.12.001.

Amfo B., Ali E.B. (2020). Climate change coping and adaptation strategies: How do cocoa farmers in Ghana diversify farm income? *Forest Policy and Economics*, 119, 102265. DOI: https://doi.org/10.1016/j.forpol.2020.102265.

Arnell N.W., Brown S., Gosling S.N., Gottschalk P., Hinkel J., Huntingford C., Lloyd-Hughes B., Lowe J.A., Nicholls R.J., Osborn T.J., Osborne T.M., Rose G.A., Smith P., Wheeler T.R., Zelazowski P. (2016). The impacts of climate change across the globe: A multi-sectoral assessment. *Climatic Change*, 134(3): 457-474. DOI: https://doi.org/10.1007/s10584-014-1281-2.

Babakholov S., Bobojonov I., Hasanov S., Glauben T. (2022). An Empirical Assessment of the Interactive Impacts of Irrigation and Climate on Farm Productivity in Samarkand region, Uzbekistan. *Environmental Challenges*, 7, 100502. DOI: https://doi.org/10.1016/j.envc.2022.100502.

Bobojonov I., Berg E., Franz-Vasdeki J., Martius C., Lamers J.P.A. (2016). Income and irrigation water use efficiency under climate change: An application of spatial stochastic crop and water allocation model to Western Uzbekistan. *Climate Risk Management*, 13: 19-30. DOI: https://doi.org/10.1016/j.crm.2016.05.004.

Bolch T., Marchenko S. (2006). Significance of glaciers, rock glaciers, and ice-rich permafrost in the Northern Tien Shan as water towers under climate change conditions. Proceedings of the Workshop Assessment of Snow-Glacier and Water Resources in Asia, 199-211. DOI: https://doi.org/10.5167/uzh-137250.

Bryan E., Ringler C., Okoba B., Roncoli C., Silvestri S., Herrero M. (2013). Adapting agriculture to climate change in Kenya: Household strategies and determinants. *Journal of Environmental Management*, 114: 26-35. DOI: https://doi.org/10.1016/j.jenvman.2012.10.036.

Delaporte I., Maurel M. (2018). Adaptation to climate change in Bangladesh. *Climate Policy*, 18(1): 49-62. DOI: https://doi.org/10.1080/14693062.2016.1222261.

Deressa T.T., Hassan R.M., Ringler C., Alemu T., Yesuf M. (2009). Determinants of farmers’ choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, 19(2): 248-255. DOI: https://doi.org/10.1016/j.gloenvcha.2009.01.002.

Djanibekov U., Dzhakypbekova K., Chamberlain J., Weyerhaueser H., Zorner R., Villamor G., Xu J. (2015). *Agroforestry for Landscape Restoration and Livelihood Development in Central Asia*. 41. DOI: https://doi.org/10.5716/WP14143.

Dougherty C., Dougherty C. (2011). *Introduction to econometrics*. Oxford University Press, USA. (Oxford Uni).

Ferdushi K.F., Ismail M.T., Kamil A.A. (2019). Perceptions, knowledge and adaptation about climate change: A study on farmers of haor areas after a flash flood in Bangladesh. *Climate*, 7(7): 1-17. DOI: https://doi.org/10.3390/cli7070085.

Garschagen M., Romero-Lankao P. (2015). Exploring the relationships between urbanization trends and climate change vulnerability. *Climatic Change*, 133(1): 37-52. DOI: https://doi.org/10.1007/s10584-013-0812-6.

Gbetibouo G.A. (2009). *Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin*, South Africa (Vol. 849). Intl Food Policy Res Inst. (IFPRI).

GC A., Yeo J.H. (2020). Perception to Adaptation of Climate Change in Nepal: An Empirical Analysis Using Multivariate Probit Model. *Sci*, 2(4). DOI: https://doi.org/10.3390/sci2040087.

Gosling S.N., Arnell N.W. (2016). A global assessment of the impact of climate change on water scarcity. *Climatic Change*, 134(3): 371-385. DOI: https://doi.org/10.1007/s10584-013-0853-x.

Hagg W., Hoelzle M., Wagner S., Mayr E., Klose Z. (2013). Glacier and runoff changes in the Rukhk catchment, upper Amu-Darya basin until 2050. *Global and Planetary Change*, 110: 62-73. DOI: https://doi.org/10.1016/j.gloplacha.2013.05.005.

Harris I., Jones P.D., Osborn T.J., Lister D.H. (2014). Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset. *International Journal of Climatology*, 34(3): 623-642.

Hill A.F., Minbaeva C.K., Wilson A.M., Satylkanov R. (2017). Hydrologic controls and water vulnerabilities in the Naryn River Basin, Kyrgyzstan: A socio-hydro case study of water stressors in central Asia. *Water (Switzerland)*, 9(5), 325. DOI: https://doi.org/10.3390/w9050325.

Huang J., Yu H., Guan X., Wang G., Guo R. (2016). Accelerated dryland expansion under climate change. *Nature Climate Change*, 6(2): 166-171. DOI: https://doi.org/10.1038/nclimate2837.

IPCC (2014). *Impacts, Adaptation, and Vulnerability*. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. https://www. ipcc. ch/site/assets/upl.

Jones D.A., Hassan O.T. (1991). Climate change and agriculture. *Trends in Ecology and Evolution*, 6(3): 101. DOI: https://doi.org/10.1016/0169-5347(91)90186-2.

Karimov B.K., Matthies M., Talskikh V., Plotsen M.A., Karimov E.B. (2019). Salinization of River Waters and Suitability of Electric Conductivity Value for Saving Freshwater from Salts in Aral Sea Basin. *Asian Journal of Water, Environment and Pollution*, 16(3): 109-114. DOI: https://doi.org/10.3233/AJW190039.

Karthe D., Chalov S., Borchardt D. (2015). Water resources and their management in central Asia in the early twenty first century: status, challenges and prospects. *Environmental Earth Sciences*, 73(2): 487-499. DOI: https://doi.org/10.1007/s12665-014-3789-1.

Khujanazarov T., Ichikawa Y., Abdullaev I., Toderich K. (2012). *Water Quality Monitoring and Geospatial Database Coupled with Hydrological Data of Zeravshan River Basin*. 202: 199-202.

Kulmatov R., Opp C., Groll M., Kulmatova D. (2013). Assessment of Water Quality of the Trans-Boundary Zarafshan River in the Territory of Uzbekistan. *Journal of Water Resource and Protection*, 05(01): 17-26. DOI: https://doi.org/10.4236/jwarp.2013.51003.

Laws R., Balance M. (2016). Central Asian Legal and Policy Responses to Climate Change * ◈ Contents ◈ *Climate Change Impacts to Central Asia and Legal and Policy Responses*, 26(2): 183-222.

Lioubimtseva E., Henebry G.M. (2009). Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations. *Journal of Arid Environments*, 73(11): 963-977. DOI: https://doi.org/10.1016/j.jaridenv.2009.04.022.

Liu W., Liu L., Gao J. (2020). Adapting to climate change: gaps and strategies for Central Asia. *Mitigation and Adaptation Strategies for Global Change*, 25(8): 1439-1459. DOI: https://doi.org/10.1007/s11027-020-09929-y.

Majid M.A., McCaffer R. (1997). Assessment of work performance of maintenance contractors in Saudi Arabia. Discussion. *Journal of Management in Engineering*, 13(5). DOI: doi.10.1061/(ASCE)0742-597X(1997)13:5(91).

Makate C., Makate M., Mango N., Siziba S. (2019). Increasing resilience of smallholder farmers to climate change through multiple adoption of proven climate-smart agriculture innovations. Lessons from Southern Africa. *Journal of Environmental Management*, 231: 858-868. DOI: https://doi.org/10.1016/j.jenvman.2018.10.069.

Mendelsohn R. (2008). The impact of climate change on agriculture in developing countries. *Journal of Natural Resources Policy Research*, 1(1): 5-19. DOI: https://doi.org/10.1080/19390450802495882.

Mirzabaev A. (2013). *Climate Volatility and Change in Central Asia: Economic Impacts and Adaptation*. PhD Thesis. Agricultural Faculty, University of Bonn, urn:nbn:de.

Mulwa C., Marenya P., Rahut D.B., Kassie M. (2017). Response to climate risks among smallholder farmers in Malawi: A multivariate probit assessment of the role of information, household demographics, and farm characteristics. *Climate Risk Management*, 16: 208-221. DOI: https://doi.org/10.1016/j.crm.2017.01.002.

Mwongera C., Shikuku K.M., Twyman J., Läderach P., Ampaire E., Van Asten P., Twomlow S., Winowiecki L.A. (2017). Climate smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate smart agriculture technologies. *Agricultural Systems*, 151: 192-203. DOI: https://doi.org/10.1016/j.agsy.2016.05.009.

Muratov S.A., Hasanov S.T., Kalandarov R., Kurbonov S.P., Usmanova A. (2023*). Economic Assessment of the Influence of Innovations on Income from Household Activities in the Framework of Digital Economy*. In Proceedings of the 7th International Conference on Future Networks and Distributed Systems (pp. 33-41). DOI: https://doi.org/10.1145/3644713.3644719.

Narama C., Kääb A., Duishonakunov M., Abdrakhmatov K. (2010). Spatial variability of recent glacier area changes in the Tien Shan Mountains, Central Asia, using Corona (~ 1970), Landsat (~ 2000), and ALOS (~ 2007) satellite data. *Global and Planetary Change*, 71(1-2): 42-54. DOI: https://doi.org/10.1016/j.gloplacha.2009.08.002.

Nautiyal Snigdha S.K. (2022). The knowledge politics of capacity building for climate change at the UNFCCC. *Climate Policy*, 22: 576-592. DOI: https://doi.org/10.1080/14693062.2022.2042176.

Ososkova T., Gorelkin N., Chub V. (2000). Water resources of Central Asia and adaptation measures for climate change. *Environmental Monitoring and Assessment*, 61(1): 161-166. DOI: https://doi.org/10.1023/A:1006394808699.

Piya L., Maharjan K.L., Joshi N.P. (2013). Determinants of adaptation practices to climate change by Chepang households in the rural Mid-Hills of Nepal. *Regional Environmental Change*, 13(2): 437-447. DOI: https://doi.org/10.1007/s10113-012-0359-5.

Pritchard H.D. (2019). Asia's shrinking glaciers protect large populations from drought stress. *Nature*, 569(7758): 649-654. DOI: https://doi.org/10.1038/s41586-019-1240-1.

Punkari M., Droogers P., Immerzeel W., Korhonen N., Lutz A., Venäläinen A. (2014). *Climate Change and Sustainable Water Management in Central Asia*. ADB Central and West Asia Working Papers, 5. http://www.adb.org/sites/default/files/projdocs/2014/44066-012-dpta-01.pdf.

Radchenko I., Dernedde Y., Mannig B., Frede H.G., Breuer L. (2017). Climate change impacts on runoff in the Ferghana Valley (Central Asia). *Water Resources*, 44(5): 707-730. DOI: https://doi.org/10.1134/S0097807817050098.

Rahut D.B., Ali A. (2017). Coping with climate change and its impact on productivity, income, and poverty: Evidence from the Himalayan region of Pakistan. *International Journal of Disaster Risk Reduction*, 24: 515-525. DOI: https://doi.org/10.1016/j.ijdrr.2017.05.006.

Reyer C.P.O., Otto I.M., Adams S., Albrecht T., Baarsch F., Cartsburg M., Coumou D., Eden A., Ludi E., Marcus R. (2017). Climate change impacts in Central Asia and their implications for development. *Regional Environmental Change*, 17(6): 1639-1650. DOI: https://doi.org/10.1007/s10113-015-0893-z.

Salokhiddinov A., Boirov R., Ismailov M., Mamatov S., Khakimova P., Rakhmatullaeva M. (2020). Climate change effects on irrigated agriculture: Perspectives from agricultural producers in eastern Uzbekistan. IOP Conference Series: *Earth and Environmental Science*, 612(1). DOI: https://doi.org/10.1088/1755-1315/612/1/012058.

Schlaepfer D.R., Bradford J.B., Lauenroth W.K., Munson S.M., Tietjen B., Hall S.A., Wilson S.D., Duniway M.C., Jia G., Pyke D.A., Lkhagva A., Jamiyansharav K. (2017). Climate change reduces extent of temperate drylands and intensifies drought in deep soils. *Nature Communications*, 8. DOI: https://doi.org/10.1088/1755-1315/612/1/01205810.1038/ncomms14196.

SCRUz (2022). *The State Committee of the Republic of Uzbekistan on Statistics*. Tashkent.

Seddon A.W.R., Macias-Fauria M., Long P.R., Benz D., Willis K.J. (2016). Sensitivity of global terrestrial ecosystems to climate variability. *Nature*, 531(7593): 229-232. DOI: https://doi.org/10.1038/nature16986.

Sherzod B. (2021). *Climate Change Impacts and Agriculture: Empirical Evidence from Zarafshan River Basin*, Uzbekistan. 9(2): 7-16. DOI: https://doi.org/10.1062/1151-1/131989.

Sherzod B., Kim K.-R., Lee S.H. (2018). Agricultural transition and technical efficiency: An empirical analysis of wheat-cultivating farms in Samarkand Region, Uzbekistan. *Sustainability (Switzerland)*, 10(9). DOI: https://doi.org/10.3390/su10093232.

Siegfried T., Bernauer T., Guiennet R., Sellars S., Robertson A.W., Mankin J., Bauer-Gottwein P., Yakovlev A. (2012). Will climate change exacerbate water stress in Central Asia? *Climatic Change*, 112(3-4): 881-899. DOI: https://doi.org/10.1007/s10584-011-0253-z.

Smit B., Skinner M.W. (2002). Adaptation options in agriculture to climate change: A typology. *Mitigation and Adaptation Strategies for Global Change*, 7(1): 85-114. DOI: https://doi.org/10.1023/A:1015862228270.

Sommer R., Glazirina M., Yuldashev T., Otarov A., Ibraeva M., Martynova L., Bekenov M., Kholov B., Ibragimov N., Kobilov R., Karaev S., Sultonov M., Khasanova F., Esanbekov, M., Mavlyanov D., Isaev S., Abdurahimov S., Ikramov R., Shezdyukova L., de Pauw E. (2013). Impact of climate change on wheat productivity in Central Asia. *Agriculture, Ecosystems and Environment*, 178: 78-99. DOI: https://doi.org/10.1016/j.agee.2013.06.011.

Sorg A., Bolch T., Stoffel M., Solomina O., Beniston M. (2012). Climate change impacts on glaciers and runoff in Tien Shan (Central Asia). *Nature Climate Change*, 2(10): 725-731. DOI: https://doi.org/10.1038/nclimate1592.

Sutton W.R., Srivastava J.P., Neumann J.E. (2013). *Looking beyond the horizon: How climate change impacts and adaptation responses will reshape agriculture in eastern Europe and central Asia*. World Bank Publications. DOI: https://doi (print) 10.1596/978-0-8213-9768-8.

Tesfaye W., Seifu L. (2016). Climate change perception and choice of adaptation strategies: Empirical evidence from smallholder farmers in east Ethiopia. *International Journal of Climate Change Strategies and Management*, 8(2): 253-270. DOI: https://doi.org/10.1108/IJCCSM-01-2014-0017.

UzHydro-Met (2018). Centre of Hydrometeorological Service, Cabinet of Ministers, 2018. Second National Communication of the Republic of Uzbekistan under the United Nations Framework Convention on Climate Change, Tashkent.

World Bank (2018a). https://climateknowledgeportal.worldbank.org/watershed/161/climate-data-historical.

World Bank Group (2021). *Climate Risk Country Profile: Uganda*. The World Bank Group, 36. www.worldbank.org.

Xenarios S., Gafurov A., Schmidt-Vogt D., Sehring J., Manandhar S., Hergarten C., Shigaeva J., Foggin M. (2019). Climate change and adaptation of mountain societies in Central Asia: uncertainties, knowledge gaps, and data constraints. *Regional Environmental Change*, 19(5): 1339-1352. DOI: https://doi.org/10.1007/s10113-018-1384-9.

Yegbemey R.N., Yabi J.A., Tovignan S.D., Gantoli G., Haroll Kokoye S.E. (2013). Farmers' decisions to adapt to climate change under various property rights: A case study of maize farming in northern Benin (West Africa). *Land Use Policy*, 34: 168-175. DOI: https://doi.org/10.1016/j.landusepol.2013.03.001.

Zhang C., Ren W. (2017). Complex climatic and CO2 controls on net primary productivity of temperate dryland ecosystems over central Asia during 1980-2014. *Journal of*

Geophysical Research: Biogeosciences, 122(9): 2356-2374. DOI: https://doi.org/10.1002/2017JG003781.

Zhang M., Chen Y., Shen Y., Li B. (2019). Tracking climate change in Central Asia through temperature and precipitation extremes. *Journal of Geographical Sciences*, 29(1): 3-28. DOI: https://doi.org/10.1007/s11442-019-1581-6.