KOCHI UNIVERSITY OF TECHNOLOGY

Social Design Engineering Series SDES-2024-2

Farm sizes and adaptation responses to climate change in agriculture: A reflection of Tajikistan's farming culture and history

Husniddin Sharofiddinov
School of Economics and Management, Kochi University of Technology
Scientific research Institute for hydraulic engineering and melioration "TajikNIIGiM", Republic of Tajikistan

Moinul Islam
School of Economics and Management, Kochi University of Technology
Research Institute for Future Design, Kochi University of Technology

Koji Kotani
School of Economics and Management, Kochi University of Technology
Research Institute for Future Design, Kochi University of Technology
Urban Institute, Kyushu University
College of Business, Rikkyo University

May 15, 2024

School of Economics and Management
Research Institute for Future Design
Kochi University of Technology

Farm sizes and adaptation responses to climate change in agriculture: A reflection of Tajikistan's farming culture and history

Husniddin Sharofiddinov[*,†] Moinul Islam[*,‡] Koji Kotani[*,‡,§,¶,‖]

May 15, 2024

Abstract

Climate change is a global concern, having a negative impact on agriculture, for food security and sustainability. Farmers' adaptations are known to be key drivers for the resolutions. However, little is established about relationships between farmers' characteristics and adaptation responses to climate change under irrigated agriculture. We investigate how farm sizes influence the adaptations in consideration to irrigation-related, cognitive and socioeconomic factors reflecting farming culture and history, hypothesizing that large-size farms adapt to climate change as compared to small-size ones in Tajikistan, where collective farming, "Kolkhoz and Sovkhoz," had been practiced. The data were collected through a questionnaire survey with 800 farmers on their adaptations, farm sizes, climatic perceptions, irrigation water availability and socioeconomic factors. We conduct statistical analyses utilizing the index to characterize farmers' adaptation responses. The results indicate an importance of farm sizes on adaptations, demonstrating that small-size farms adapt less than large-size farms, but increases their adaptations when they have good climatic perceptions and irrigation water availability. Overall, this research confirms an advantage of large-size farms for adaptations based on Tajikistan farming culture and history. Thus, the ongoing land-fragmentation policy should be reconsidered for possible losses in adaptations, as it has been drastically increasing the number of small-size farms. Otherwise, it is essential to support the small-size farms for acquiring good perceptions and enough water.

Key Words: Farm sizes; adaptation responses; farming culture; history; Tajikistan

[*]School of Economics and Management, Kochi University of Technology
[†]Scientific research Institute for hydraulic engineering and melioration "TajikNIIGiM", Republic of Tajikistan
[‡]Research Institute for Future Design, Kochi University of Technology
[§]Urban Institute, Kyushu University
[¶]College of Business, Rikkyo University
[‖]Corresponding author, E-mail: kojikotani757@gmail.com

Contents

1 Introduction **3**

2 Farming culture and history **5**

3 Data and methodology **9**

3.1 Study areas and data collection 9

3.2 Key variables 10

3.3 Conceptual framework and data analysis 15

4 Results **18**

5 Conclusion **29**

Nomenclature

AdaptInd Adaptation index

AdapNum Adaptation number

CPInd Climatic perceptions index

IWA Irrigation water availability

1 Introduction

Climate change has become a growing global concern and posed a negative impact on agriculture, for food security and sustainability (Rosegrant and Cline, 2003, Burkel and Lobell, 2010, Hanjra and Qureshi, 2010, Ziervogel and Ericksen, 2010, Sasson, 2012, Mahato, 2014, Nelson and van der Mensbrugghe, 2014, Campbell et al., 2016, Orchard et al., 2020, Din et al., 2022). It is established that climate change cannot be resolved only by mitigation (Jensen and Traeger, 2014, Fujimori et al., 2018). Rather, adaptations are keys to not only resolving climate change but also maintaining food security and sustainability under growing population with less resources, land and water availability per capita (Linnenluecke et al., 2015, Rasul and Sharma, 2016). Particularly, farmers are considered the main actors to initiate and take adaptation responses to climate change, and their cognitive and socioeconomic factors are assumed to be the important determinants depending on culture and history in each region or country (Dixon et al., 2014, Huttunen et al., 2015, Dang et al., 2019, Arnalte-Mur et al., 2020, Ardakani et al., 2020). Given this state of affairs, we seek to address how farmers take adaptations in relation to cognitive and socioeconomic factors that reflect farming culture and history.

In the last few decades, the impact of climate change on agricultural productivity has been studied, using agronomic models and statistical approaches (Moore et al., 2017, Li et al., 2023b). For instance, the statistical approaches have been used to examine farmers' adaptation responses in relation to cognitive and economic factors (Below et al., 2012, Esham and Garforth, 2013, Li et al., 2023a, Sandilya and Goswami, 2024, Sun et al., 2024). Several studies examine the relationship between climatic perceptions and the farmers' adaptations (Deressa et al., 2011, Islam et al., 2016, Datta et al., 2022). Climatic perceptions and farm sizes are the key cognitive and socioeconomic determinants for farmers' adaptations to climate change (Koirala et al., 2022). Several empirical studies have explored the adaptations in relation to farm sizes, documenting both the negative and positive results (Khan et al., 2020). The possible reasons for negative or positive results on adaptations are claimed to be specific characteristics of the study areas, such as geographic locations, cognitive and socioeconomic factors (Bobojonov and Aw-Hassan, 2014, Amare and Simane, 2017).

A group of studies have shown a negative relation between farm sizes and adaptation responses to climate change (Acquah, 2011, Deressa et al., 2011, Tesfaye and Seifu, 2016, Maya et al., 2019). Uddin et al. (2014) investigate the farmers' adaptation practices to environmental destruction and climate change by collecting a questionnaire data with 100 farmers in Bangladesh, documenting that the probability of adaptation responses decreases in large-size farms due to shortage of investments. Kabubo-Mariara and Mulwa (2019) study the factors affecting adaptations to climate change and variability by taking 658 households in Kenya as a sample, finding that an increase in farm sizes have an adverse relationship with maize grain production for both adapters and non-adapters. Koirala et al. (2022) examine adaptation responses to climate change in relation to farm sizes along with cognitive and sociodemographic factors by taking a sample of 1000 farmers in Nepal. The results indicate that small-size farms adapt with their good climatic perceptions and networking with other farmers as compared to large-size farms. Overall, these studies present that small-size farms tend to respond to climate change with less required inputs and investments as compared to large-size farms.

Another group of studies shows some positive association between farm sizes and farmers' adaptation responses to climate change (Nabikolo et al., 2012, Abid et al., 2016, Vinaya et al., 2017, Bakhsh and Kamran, 2019, Thinda et al., 2020). Several studies indicate that farm sizes, education level, access to climate information, market, subsidies and credits have positive relationship with farmers' adaptations to climate change (Alauddin and Sarker, 2014, Belay et al., 2017, Fadina and Barjolle, 2018, Marie et al., 2020, Ojo and Baiyegunhi, 2020). Ali and Erenstein (2017) investigate determinants of farmers' decisions on adaptation practices using a questionnaire survey from 950 farmers under both irrigated and rain-fed agriculture in Pakistan, presenting that the number of adaptations tends to increase in farm sizes. Trinh et al. (2018) examine some key variables that shall be considered to impact farmers' choices for adaptations in agricultural productions, taking 400 farmers from Ky Son commune in Vietnam, indicating that farmers tend to change crop varieties, switch to new cultivar types and adjust the planting time when their farm size increases. Jha and Gupta (2021) study farmers' climatic perceptions and socioeconomic factors in relation to adaptation strategies under rain-fed agriculture, collecting 700 farmers' data in seven districts of northern India. They find that large-size farms tend to implement most of the adaptation strategies, such as crop diversification, irrigation and soil management. Overall, the literature document that large-size farms tend to respond to climate change, being able to invest on technologies, machinery, infrastructures and other inputs, as compared to small-size farms.

Agricultural sector have been reported to be one of the most vulnerable sectors against climate change. Thus, it is important to understand how farmers are induced to take adaptation responses under modern agriculture and to take proper countermeasures for food security and sustainability. While there are a series of articles to present some mixed results, little is established about relationships between farmers' characteristics and adaptation responses to climate change under irrigated agriculture. Given this paucity in the literature, we examine how farm sizes characterize the adaptations in consideration to irrigation-related, cognitive and socioeconomic factors reflecting farming culture and history. To this end, we conduct a questionnaire survey with 800 farmers in the two river basins of Tajikistan and collect data on their adaptation practices, farm sizes, climatic perceptions (CPInd), irrigation water availability (IWA), cognitive and socioeconomic variables. We conduct econometric analyses, employing an index which reflects the coverage areas by farmers' adaptation responses. This research hypothesizes that large-size farms adapt to climate change as compared to small-size ones under irrigated agriculture in Tajikistan, "Kolkhoz and Sovkhoz," had been practiced. Answering the question and hypothesis shall be useful for guiding the ongoing debate regarding land-fragmentation and adaptation policies in not only Tajikistan but also other nations facing similar problems towards sustainable development goals (SDGs).

2 Farming culture and history

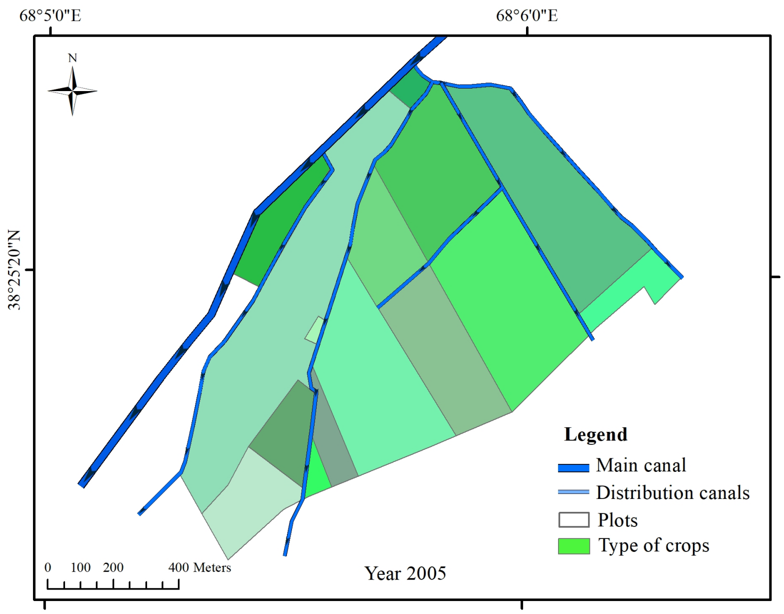
Tajikistan is a landlocked country in Central Asia and 93 % of its territory is covered with mountains. While the agriculture is engaged in non-mountainous areas, i.e., the rest of 7 %, Tajikistan is still considered an agricultural country with a population of more than 10 million. Agriculture is the backbone of Tajikistan economy, contributing 24 % of the gross domestic product (GDP) and employing 46 % of the population (World Bank, 2021). The total potential area suitable for irrigation is estimated to be 1.57 million ha out of which 0.76 million ha is developed at present. In Tajikistan, the availability of irrigated land per capita is 0.08 ha which is the lowest among Central Asian countries (ALRI, 2020). Irrigated agriculture is critical for food security and sustainability, providing more than 80 % of Tajikistan agricultural production (MEDT, 2013).

Development of large irrigation systems during the Soviet era had played an important role on improving food security and sustainability through transforming Tajikistan agriculture into being one of the main sectors. The development of vast tracts in the northern and southern regions demonstrated an economically profitable practice for the agricultural development in the past. The implementation of state programs on construction of the large irrigation systems has began from 1930, including canals, pump stations, reservoirs and other supplementary infrastructures. In parallel, a collectivization process took place on merging small and inefficient individual farms into a large state one, such as collective state farms (Kolkhoz and Sovkhoz) along with mechanization and processing. The state agricultural enterprises had achieved a steady increase in productivity, an increase in the gross harvest of agricultural products, having made not only a great contribution to strengthening the food security of the states but also served as a model of cultures for collective farms (Sulaymonshoev, 2011, Alimov, 2020).

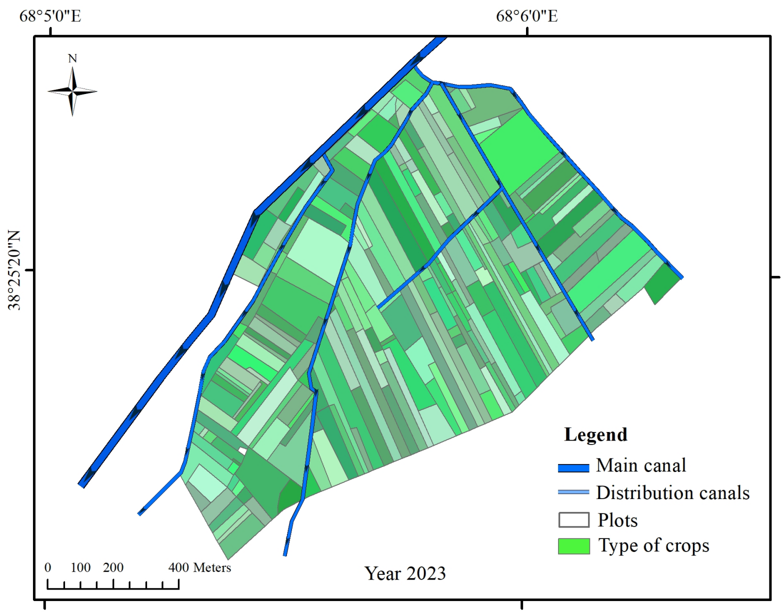
For the development and management of the agricultural sector during the Soviet Union period, some designated ministries had been working jointly with scientific-research institutes and experimental stations (Sotnikov, 1960). The collective and state farms had an adequate natural capital to accelerate their material-technical bases including mechanized parks, storage, product processing, cattle, poultry and seed breeding centers. In the 1970 - 1980, most of collective farms had good-quality agricultural specialists with high education. Such specialists were economists, agronomists and engineers and they were working on mechanization, irrigation and livestock management with farmers. For instance, the irrigation specialists were responsible for controlling, monitoring and supervising water allocations within the farms as well as for improving water use efficiency. The agronomists were responsible for controlling, monitoring and supervising crop adjustments and rotations, sowing and harvesting times, soil reclamation, breeding crop varieties, pests management as well as adaptations to weather changes. Overall, agricultural sector was managed in a complex manner from planning to productions by the Soviet Union. However, the centralized approach had the pros and cons depending on the temporal changes through implementations of various policies in some regions. The agricultural sector was known to have faced huge challenges, such as inefficiencies, resource mismanagement and a lack of controls, and it became noncompetitive in a globalized agricultural market after the Soviet Union (Rowe, 2010).

The collapse of the Soviet Union has been marked by political, institutional and sectoral changes along with the degradation of government support during the transition from a centralized to a market-based economy and have created significant challenges to agriculture in Tajikistan. In the transitions, Tajikistan government had started decentralizing agricultural sector through adopting a series of state policies and programs for a land reform. The main goal of the land reform was to increase agricultural production, the degree of freedom for farmers, crop diversification and efficient use of natural resources (land and water). Following the decentralization, the collective and state farms were reorganized to individual small-size farms. The number of farms had increased from 5713 in 1997 to 187 220 in 2020, while irrigated land has increased only a little from 719 000 ha to 763 000 ha (SCLMG, 2020).

Figure 1a demonstrates an example where one specific area of 120 ha in the upstream region of Kofarnihon river basin consisted of 15 plots with an average size of 8 ha, and it was part of one collective farm in 2005. Figure 1b show that the irrigation system including distribution canals remains unchanged from 2005 to 2020, while the number of plots has increased up to 237 with an average size of 0.5 ha in 2023. It implies that the area becomes highly fragmented through the land reform with an increasing number of small-size farms. In other words, the average plot size has decreased approximately by 94 %. Consequently, several salient problems, such as the lack of appropriate infrastructure, problems related to water allocations, equipment and services, limited



(a) Plot sizes in 2005



(b) Plot sizes in 2023

Figure 1: Changing plot sizes from 2005 to 2023 and irrigation systems. Source: Google Earth images for Kofarnihon river basin

information access and uncertainties, have persisted, and it is claimed that Tajikistan farms become less capable of adapting to external factors for food security and sustainability. To examine the claim, it is essential to study and understand the relationship between farm sizes and adaptations to climate change for identifying a path to SDGs, considering an ongoing land-reform policy in Tajikistan.

3 Data and methodology

3.1 Study areas and data collection

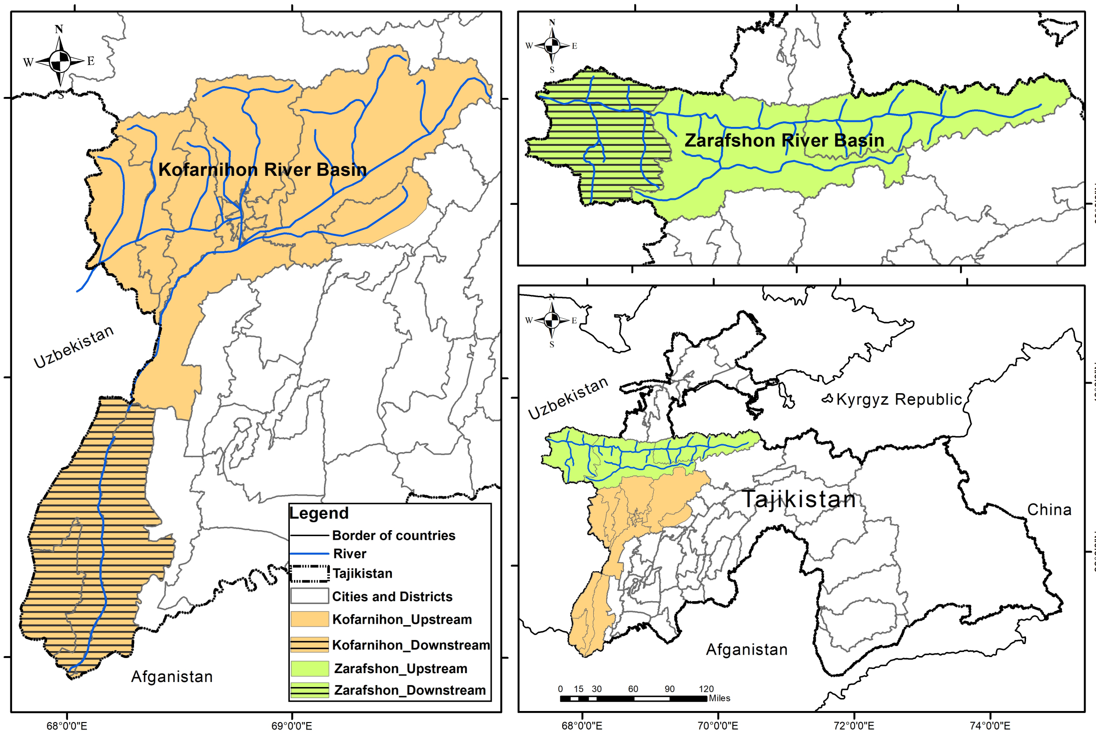
In Tajikistan, the five river basin management organizations (Syrdarya, Zarafshon, Kofarnihon, Vakhsh and Panj) were created for the proper planning and effective management of water resources. These river basin organizations are based on the hydrological and regional administrative boundaries, considering hydrotechnical infrastructures, water use and economic circumstances. Among them, Kofarnihon and Zarafshon river basins are chosen as our study areas. Kofarnihon river basin is located in the central-southwest part, covering over 30 % of Tajikistan territory. The climate is continental in the basin, being characterized by large fluctuations of daily and seasonal air temperatures as well as uneven distribution of precipitations throughout a year. The average minimum air temperature is −12.1 °C and the absolute maximum reaches 41 °C in the upstream regions, while the average minimum air temperature is 1.8 °C to 1.9 °C and the absolute maximum temperature reaches 47 °C in the downstream regions. The average annual precipitations range between 252 mm and 1188 mm in the downstream and upstream regions, respectively (Gulakhmadov et al., 2020). Zarafshon river basin is located in the central-western part of Tajikistan, covering approximately 9 % of Tajikistan territory. The average minimum air temperature is −12.1 °C and the absolute maximum reaches 35 °C in the upstream regions, while the average minimum air temperature is −1 °C and the absolute maximum temperature reaches 47 °C in the downstream regions. The average annual precipitations range between 600 mm and 159 mm in the upstream and downstream regions, respectively (Normatov et al., 2023).

A stratified sampling method was utilized to conduct our questionnaire surveys in Kofarnihon and Zarafshon river basins (see figure 2). We consider both upstream and downstream regions of Kofarnihon and Zarafshon river basins as the best possible proxy to approximate representative agriculture with climatic zones from small-size to large-size farms in Tajikistan. A list of farmers under irrigated areas was collected from each of the two river basins with support from the Ministry of Energy and Water Resources and Agency for Land Reclamation and Irrigation. We randomly selected 800 farmers with the strata of the upstream and downstream regions as well as the unequal numbers of farms over the basins. As a consequence, 487 and 313 farmers were selected from the upstream and downstream regions, respectively, and a simple random sampling within each stratum was applied to finalize the sample selection for our data collection. Because the two basins have unequal numbers of farms, we sought to reflect the difference through the above stratified sampling procedures. We conducted the orientation sessions over two days, training research assistants and conducting pretests of the questionnaires. The surveys had been conducted from May 15 to June 14, 2024 with local Tajikistan language. The 1st author administered the orientation sessions and surveys, organizing the research assistants for interviewing farms.

3.2 Key variables

The heads of farms (hereafter, farmers) were asked a series of questions related to their farm sizes, adaptations and the corresponding areas. A list of adaptations is prepared following Below et al. (2012) and Koirala et al. (2022). On top of it, we include some new adaptations, such as “night irrigation,” “drip irrigation,” and “film farming,” taking the farmers’ suggestions during the orientation sessions and field observations by the 1st author. In total, 34 adaptations are considered across water management, soil management and crop adjustment and diversification for the analyses (see table 1 for the list). We also collect information related to cognitive and socioeconomic factors of climatic perception index (CPInd), farming experience, information access, education, irrigation water availability (IWA), equipment and services, distance to plots, income source, family size, gender and climatic zones (see table 2 for the details). We provide a list of adaptations to

Figure 2: A map of study areas in Tajikistan



farmers, asking them to indicate their adaptation practices and its area coverage (Below et al., 2012, Koirala et al., 2022). With the information, the key variables of adaptation number (AdaptNum) and adaptation index (AdaptInd) in our statistical analyses are derived.

The AdaptNum for the i^{th} farmer is calculated as follows:

$$\text{AdaptNum}_i = \sum_{h=1}^{34} a_{hi} \tag{1}$$

where subscript h denotes an index of adaptations from 1 to 34 and a_{hi} is a dummy variable for adaptation h, taking 1 when the i^{th} farmer adopts the adaptation, otherwise, 0. The AdaptInd for the i^{th} farmer is calculated as follows:

$$\text{AdaptInd}_i = \sum_{h=1}^{34} a_{hi} w_{hi} \tag{2}$$

where $w_{hi} = \frac{\text{Area coverage by } a_{hi}}{\text{Total cultivated area of the } i^{\text{th}} \text{ farmer}} \in [0, 1]$. Equations (1) and (2) imply that both AdaptNum_i and AdaptInd_i range between 0 and 34. The AdaptNum_i is the summation of adaptations, while the AdaptInd_i is a weighted average of adaptations by w_{hi} for the i^{th} farmer.

The other key variables in our study shall be farm sizes, CPInd and IWA. We find that there is no official categorization of farm sizes in Tajikistan. Based on our field observations and discussions with staff from the Ministry of Agriculture of the Republic of Tajikistan, we decide to categorize farm sizes into three groups, creating two farm-size dummies along with one base group: (i) large-size farms (farm sizes $>$ 3 ha) as a base group, medium-size farms (3 ha $\geq$ farm sizes $\geq$ 1 ha) as the medium-size dummy and small-size farms (farm sizes $<$ 1 ha) as the small-size dummy (see table 2). Regarding CPInd, we ask farmers to answer 10 questions on their perceived changes in summer and winter temperatures, precipitations, rainfall frequency and intensity, snowfall frequency and intensity, drought, cold waves and hot waves over the last 10 years, following the approach by Koirala et al. (2022) and the pretesting of our questionnaires. Farmers report their perceptions on the changes in these climatic factors, and we assign 1 for the perceived "change," otherwise 0 (see table 2). Finally, we calculate CPInd to be the summation of their answers from

Table 1: Percentages of farms that implement adaptation practices by their sizes

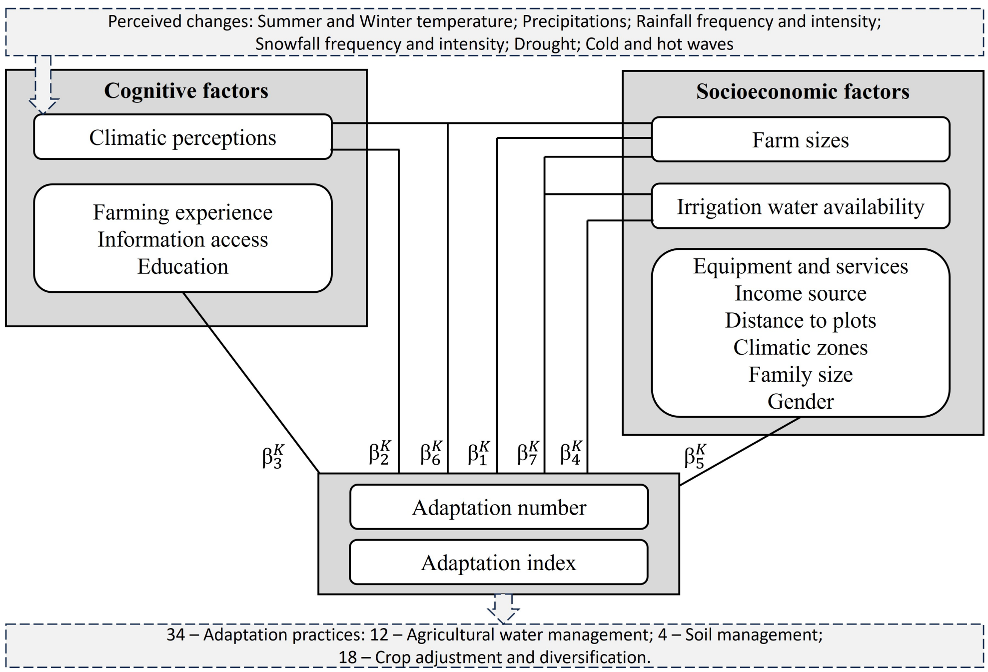
Adaptation practices	Percentages (%)			
	Large-size farm ($N = 261$)	Medium-size farm ($N = 394$)	Small-size farm ($N = 144$)	Overall ($N = 799$)
Agricultural water management				
Night irrigation	81.99	67.51	55.56	70.09
Bucket irrigation	0.77	1.78	9.72	2.88
Construction of reservoirs and channels	0.00	0.51	0.00	0.25
Diversion ditches	4.60	6.09	11.81	6.63
Hedges	16.86	4.06	2.08	7.88
Use of vertical wells and pumps	4.98	2.54	0.69	3.00
Drip Irrigation	1.15	0.25	0.00	0.50
Runoff harvesting	0.77	0.25	0.00	0.38
Destocking (drainage cleaning)	15.71	20.05	22.92	19.15
Aquaculture	3.45	3.05	14.58	5.26
Winter irrigation (Freezing)	58.62	22.59	19.44	33.79
Mulching	1.92	3.05	2.08	2.50
Soil management				
Deep tillage (30-35sm)	88.52	50.76	29.17	57.57
Crop rotation	71.26	52.03	34.03	55.07
Extend farmland outside of the ward	2.68	3.81	2.78	3.25
Restoration of degraded lands	3.07	0.76	0.69	1.50
Crop adjustment and diversification				
Cultivation of high-quality crops	19.92	34.77	25.69	28.25
Crop breeding	3.45	1.78	1.39	2.25
Planting short-term variety crops	5.36	6.60	4.17	5.76
Planting early crops	6.90	14.47	3.47	10.01
Planting high yielding varieties	6.90	15.74	7.64	11.39
Cover crops	2.68	0.51	0.69	1.25
Film farming	4.60	2.28	0.00	2.63
Adjustment to sowing date	71.65	55.58	50.00	59.82
Adoption of different varieties (drought/ pest/ heat stress resistant)	3.07	9.64	10.42	7.63
Cultivation of cold-resistant crops	3.07	2.54	4.17	3.00
Cereal crop production	67.43	55.33	38.19	56.20
Revegetation	56.70	47.21	36.11	48.31
Grow vegetables in off season	1.53	2.54	1.39	2.00
Mix cropping	14.18	6.60	11.11	9.89
Apply farm yard manure/ organic fertilizer	92.72	89.85	92.36	91.24
Apply inorganic fertilizer	90.04	90.36	91.67	90.49
Keep livestock	25.67	53.81	59.72	45.68
Keep bee farming	1.53	2.28	2.08	2.00

Notes: Large-size farm (farm sizes $>$ 3 ha), medium-size farm (3 ha $\geq$ farm sizes $\geq$ 1 ha),small-size farm (farm sizes $<$ 1 ha).

Table 2: Definitions of the variables

Variables	Definitions and descriptions
Dependent variables	
Adaptation number (AdaptNum)	A total number of adaptations taken by the farmer.
Adaptation index (AdaptInd)	The farmer's aggregate index value is determined by summing up all adaptations, each weighted according to its proportion coverage relative to the farm sizes.
Independent variables	
Farm-size variables	
Large-size farm (base group)	A dummy variable that takes value 1 if farm sizes is >3 ha; otherwise, 0.
Medium-size farm	A dummy variable that takes value 1 if farm sizes is ≤ 3 ha & ≥ 1 ha; otherwise, 0.
Small-size farm	A dummy variable that takes value 1 if farm sizes is <1 ha; otherwise, 0.
Cognitive variables	
Climatic perception index (CPInd)	Various changes in temperature, rainfall, snowfall, drought, hot waves and cold waves perceived by farmer over the last 10 years, rated on a scale of 0 to 10.
Farming experience	The level of agricultural experience for the farmer ranges between 1-5. 1 - less than five years; 2 - 5 to 10 years; 3 - 11 to 15 years; 4 - 16 to 20 years; 5 - more than 20 years
Information access	An aggregate number of access on agricultural information in local, region, province and country levels that ranges between 0 - 32.
Education	The level of schooling for the farmer ranges between 1-4, 1 - primary school; 2 - middle school; 3 - high school; 4 - university or above.
Socioeconomic variables	
Irrigation water availability (IWA)	The level of water availability ranges between 1-5 1 - water does not reach and 5 - water abundant.
Equipment and services	Summation of the number of farmers equipment types and received agricultural services.
Distance to plots	Distance in kilometers (km) from farmers home to their land.
Income source (base group = non agriculture)	A variable that takes value 1 if the farmers' main income is from agriculture; otherwise, 0.
Climatic zones (base group = upstream)	A dummy variable that takes value 1 if the farmer is located in downstream; otherwise, 0.
Family size	The number of family members of the farmer.
Gender (base group = male)	A dummy variable that takes value 1 if the farmer is female; otherwise, 0.

Figure 3: A conceptual framework that describes the relationships between the variables (farm sizes, climatic perceptions, farming experience, information access, education, irrigation water availability, equipment and services, income source, distance to plots, climatic zones, family size, gender and interactions) and adaptation number (AdaptNum) or adaptation index (AdaptInd) by β_j^Ks for $K = \{\text{AdaptNum}, \text{AdaptInd}\}$ and $j = 0, 1, \ldots, \ell$.



10 questions (Below et al., 2012, Koirala et al., 2022). The information on IWA is collected using an ordinal five-point scale that represents 1 "water scarce," ... and 5 "water abundant" (see table 2). We use this way mainly due to the lack of other measurements for water availability at farm level in Tajikistan.

3.3 Conceptual framework and data analysis

Figure 3 introduces a conceptual framework for our empirical analyses on the basis of the observations for farmers in Tajikistan as well as some existing theories in adaptations. Tajikistan farmers are known to have different objectives in their farming activities, being similar to other countries' cases (Solano et al., 2001, Mandryk et al., 2014). Some farmers prioritize food security along with their consumptions owning to various circumstances and situations, meaning that their objectives are maximizing food production. On the other hand, other farmers focus on minimizing the risks, trying to avoid food production below certain thresholds as their 1st priority or stably ensuring a certain level of cash incomes as their side businesses. Therefore, economic theories of profit maximization and cost minimization cannot be directly and uniformly applied to adaptations in Tajikistan. Following Koirala et al. (2022), we refer to some theories in sociocognitive models, such as protection motivation theory and private proactive adaptation theory, for the conceptual framework in this study. These approaches consider cognitive and socioeconomic factors to be determinants of adaptation responses to external changes (Rogers, 1983, Rogers and Prentice-Dunn, 1997, Grothmann and Patt, 2005). Previous studies also underscore that such cognitive and socioeconomic factors are important for farmers' adaptations in agriculture (Amare and Simane, 2017, Belay et al., 2017, Ojo and Baiyegunhi, 2020).

The conceptual framework is developed to offer a comprehensive perspective for understanding how AdaptNum and AdaptInd are characterized by cognitive and socioeconomic variables along with their interactions. To this end, we apply Poisson and median regressions to quantitatively estimate parameters β_j^Ks for $j = 0, 1, \ldots, \ell$ and $K = \{\text{AdaptNum}, \text{AdaptInd}\}$, each of which represents the relationship between the AdaptNum or AdaptInd as a dependent variables and the independent variables as specified in equations (3) and (4). For AdaptNum, we select a Poisson-regression approach, because it is a variable of nonnegative integers and there are only a limited number of observations for each count. In other words, it is assumed that AdaptNum follows a Poisson distribution conditional on a vector of some independent variables, $\mathbf{X}$, with the following specification:

$$\mathrm{Prob}(\text{AdaptNum}_i = h|\mathbf{X} = \mathbf{x}_j) = \exp[-\exp(\mathbf{x}_i\beta^{K\prime})][\exp(\mathbf{x}_i\beta^{K\prime})]^h/h!, \tag{3}$$

where $K = \text{AdaptNum}$, $h = 0, 1, \ldots, 34$ is the number of adaptations the i^{th} farmer takes, $\mathbf{x}_i = (1, x_{1i}, x_{2i}, \ldots, x_{\ell i})$ is a vector of $\ell + 1$ independent variables consisting of intercept, farm-size, CPInd, IWA, cognitive, socioeconomic variables and the corresponding interaction terms, respectively. Finally, $\beta^K = (\beta_0^K, \beta_1^K, \ldots, \beta_\ell^K)$ is a vector of the coefficients associated with $\mathbf{x}_i$ to be estimated. The estimate for each coefficient is obtained through the quasi-maximum likelihood estimation method for the Poisson regression based on equation (3) (Wooldridge, 2019). We calculate a marginal effect of one independent variable on AdaptNum from each estimated coefficient, when the independent variable increases by one unit or from zero to one, holding other independent variables at their sample means.

For AdaptInd, a median regression is employed to characterize the relationship with the same set of independent variables we use in equation (3). The median regression is known to be preferred over the mean-based regression for characterizing a nonnormally distributed dependent variable in relation to some independent variables (Sarker et al., 2012, Hirose et al., 2023). Because AdaptInd is identified not to follow a normal distribution according to the Shapiro-Wilk test, we judge that the median regression approach is proper in our analysis (Corder and Foreman, 2014, Khatun, 2021). The regression specification is expressed as follows:

$$\mathrm{AdaptInd}_i = \mathbf{x}_i \beta^{K\prime} + \epsilon_i \tag{4}$$

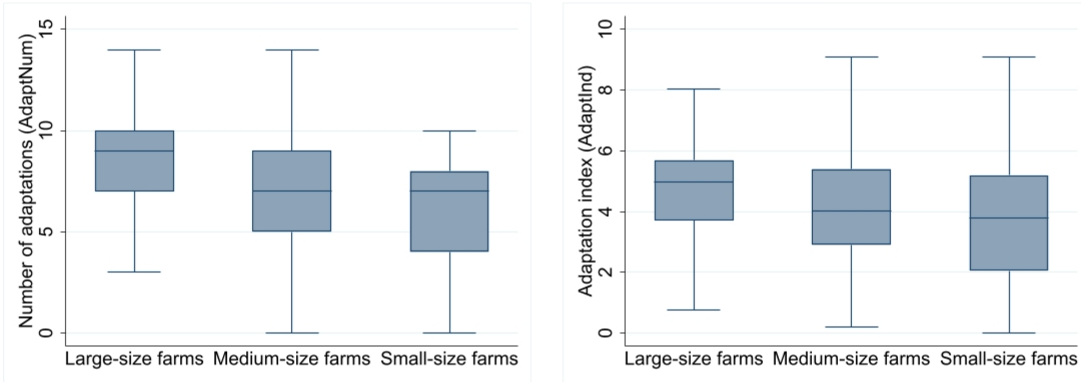
where $\mathrm{AdaptInd}_i$ is the adaptation index the i^{th} farmer takes, $\mathbf{x}_i = (1, x_{1i}, x_{2i}, \ldots, x_{\ell i})$ represents a vectors of $\ell + 1$ independent variables consisting of intercept, farm-size, CPInd, IWA, cognitive, socioeconomic variables and the corresponding interaction terms, respectively. Finally $\beta^K = (\beta_0^K, \beta_1^K, \ldots, \beta_\ell^K)$ is a vector of the coefficients associated with $\mathbf{x}_i$ to be estimated through the least absolute distance estimation method, $K = \mathrm{AdaptInd}$, and ϵ_i is an error term. Each coefficient is interpreted as a change in the AdaptInd median when one continuous (or dummy) independent variable increases by one unit (or from zero to one), holding other variables constant.

The conceptual framework depicted in figure 3 and the regression specifications outlined in equations (3) and (4) enable us to determine the crucial factors for addressing the research question and hypothesis in our study. We proceed to take the following steps. First, we conduct Mann-Whitney non-parametric tests to determine some qualitative relations between the key variables

(Conover and Iman, 1981). Second, we apply Shapiro-Wilk tests to judge whether or not AdaptInd is normally distributed (Shapiro and Wilk, 1965). Third, we estimate four regression models for each of AdaptNum and AdaptInd to be a dependent variable as robustness check: Model 1 includes farm-size dummies as the independent variables along with an intercept. Model 2 additionally includes cognitive variables. Model 3 additionally includes cognitive and socioeconomic variables. In model 4, to further characterize how the relationship between farm-size dummies and dependent variables changes, we include interaction terms between farm-size variables and CPInd as well as those between farm-size variables and IWA on top of the specifications in model 3.

4 Results

Table 1 present the percentages of farms that implement certain adaptations by their sizes. For instance, about 82 % of large-size farms use irrigation at night as an adaptation, and the percentages for medium and small-size farms are 67.51 % and 55.56 %, respectively. About 89 % of large-size farms are practicing deep tillage, while the percentages are 50.76 % and 29.17 % for medium and small-size farms, respectively. Only about 3 % of large-size farms are reported to implement adoption of different varieties that include crops resistant to drought, pest and heat stresses, and the percentages are 9.64 % and 10.42 % for medium and small-size farms, respectively. Table 1 reveal that some adaptations, such as night irrigation, deep tillage, crop rotation, adjustment to sowing date, cereal crop production and use of fertilizers, are popular as adaptation practices among farms in Tajikistan (Construction of reservoirs and channels, drip irrigation, runoff harvesting, restoration of degraded lands and cover crops, are not popular). The results appear to reflect the cost of each practice, specific environment, climate and farming history and culture, demonstrating the wide variation of the percentages in most practices by farm sizes. Overall, large-size farms are dominant with respect to the percentage in 16 practices out of 34 ones. On other hand, small-size farms are dominant only in 5 practices, and for the remaining 13 practices, clear-cut tendencies across farm sizes are not observed. Overall, the percentages of adaptation practices can be said to have some



(a) Adaptation number

(b) Adaptation index

Figure 4: Boxplots for the number of adaptations (AdaptNum) and the adaptation index (AdaptInd)

linkage with farm sizes.

Table 3 indicates that the total sample size is 799, while 261, 394 and 144 observations are collected for the large, medium and small-size farms, respectively. Farmers take 7.32 adaptations on average and the median is 8. The averages (medians) for large, medium and small-size farms are 8.41 (9.00), 7.09 (7.00) and 5.98 (7.00), respectively, implying that AdaptNum displays an upward trend as the farm size increases. Boxplots in figure 4a also confirm the same trend by farm sizes. The average AdaptInd for farmers is 4.22, and the median is 4.40. The averages (medians) are 4.62 (4.97), 4.18 (4.01) and 3.60 (3.80) for large, medium and small-size farms, respectively. Thus, the statistics indicate that AdaptInd is also likely to increase with farm sizes, being in line with the trend in the boxplots (figure 4b). Therefore, the trends in AdaptNum and AdaptInd over farm sizes are considered consistent with each other on the basis of the summary statistics and figure 4. To statistically assess the distributional differences of AdaptNum and AdaptInd among the farm sizes, we employ a nonparametric Mann-Whitney test for each pair of small-size, medium-size and large-size farms. The null hypothesis is that the distributions of AdaptNum (or AdaptInd) between different-sized farms are the same. The results show that the null hypothesis is rejected for every pair at 1 % level, implying that the distributions of AdaptNum (or AdaptInd) differ across farm sizes.

The average climatic perception index (CPInd) for farmers is 8.28, and the median is 9.00. The

Table 3: Summary statistics of the variables

	Farm-size dummy			
	Large-size farm ($N = 261$)	Medium-size farm ($N = 394$)	Small-size farm ($N = 144$)	Overall ($N = 799$
Dependent variables				
Adaptation number (AdaptNum)				
Mean (Median) [a]	8.41 (9.00)	7.09 (7.00)	5.98 (7.00)	7.32 (8.00)
SD [b]	2.61	2.53	2.59	2.71
Min	2.00	0.00	0.00	0.00
Max	18.00	16.00	10.00	18.00
Adaptation index (AdaptInd)				
Mean (Median)[a]	4.62 (4.97)	4.18 (4.01)	3.60 (3.80)	4.22 (4.40)
SD[b]	1.66	1.87	1.99	1.86
Min	0.17	0.20	0.00	0.00
Max	9.87	9.5	9.09	9.87
Independent variables				
Cognitive variables				
Climatic perception index (CPInd)				
Mean (Median)	8.42 (9.00)	8.36 (9.00)	7.79 (8.00)	8.28 (9.00)
SD	1.89	2.05	2.19	2.04
Min	0.00	0.00	0.00	0.00
Max	10.00	10.00	10.00	10.00
Farming experience				
Mean (Median)	4.21 (5.00)	4.04 (5.00)	3.89 (5.00)	4.06 (5.00)
SD	1.07	1.23	1.27	1.19
Min	1.00	1.00	1.00	1.00
Max	5.00	5.00	5.00	5.00
Information access				
Mean (Median)	6.35 (6.00)	4.24 (4.00)	3.83 (3.00)	4.86 (4.00)
SD	2.94	2.67	2.79	2.97
Min	0.00	0.00	0.00	0.00
Max	17.00	15.00	12.00	17.00
Education				
Mean (Median)	3.10 (3.00)	2.91 (3.00)	3.01 (3.00)	2.99 (3.00)
SD	0.78	0.81	0.77	0.79
Min	2.00	2.00	1.00	1.00
Max	4.00	4.00	4.00	4.00
Socioeconomic variables				
Irrigation water availability (IWA)				
Mean (Median)	3.25 (4.00)	3.43 (4.00)	3.34 (3.00)	3.35 (4.00)
SD	1.09	0.96	0.78	0.98
Min	1.00	1.00	1.00	1.00
Max	5.00	5.00	5.00	5.00
Equipment and services				
Mean (Median)	4.00 (4.00)	3.10 (3.00)	3.02 (3.00)	3.38 (3.00)
SD	1.38	1.11	1.23	1.30
Min	1.00	1.00	1.00	1.00
Max	9.00	7.00	8.00	9.00
Income source (base group = not agriculture)				
Mean (Median)	0.92 (1.00)	0.69 (1.00)	0.44 (0.00)	0.72 (1.00)
SD	0.26	0.46	0.49	0.44
Min	0.00	0.00	0.00	0.00
Max	1.00	1.00	1.00	1.00
Distance to plots				
Mean (Median)	2.38 (1.50)	1.77 (1.00)	1.38 (1.00)	1.91 (1.00)
SD	3.05	2.99	1.31	2.83
Min	0.00	0.01	0.00	0.00
Max	26.00	40.00	8.00	40.00
Family size				
Mean (Median)	9.57 (8.00)	9.24 (8.00)	7.97 (7.00)	9.12 (8.00)
SD	5.36	4.51	3.81	4.72
Min	3.00	2.00	2.00	2.00
Max	40.00	30.00	25.00	40.00
Gender (base group = male)				
Mean (Median)	0.09 (0.00)	0.22 (0.00)	0.32 (0.00)	0.19 (0.00)
SD	0.29	0.41	0.47	0.39
Min	0.00	0.00	0.00	0.00
Max	1.00	1.00	1.00	1.00

[a] Median in parentheses.
[b] SD stands for standard deviation.
Notes: Large-size farm (farm sizes $>$ 3 ha), medium-size farm (3 ha $\geq$ farm sizes $\geq$ 1 ha),small-size farm (farm sizes $<$ 1 ha).

averages (medians) are 8.42 (9.00), 8.36 (9.00) and 7.79 (8.00) for the large, medium and small-size farms, respectively, meaning that farmers tend to have high CPInd as farm size increases. The averages (medians) of irrigation water availability (IWA) for large, medium and small-size farms are 3.25 (4.00), 3.43 (4.00) and 3.34 (4.00), respectively. The results show that there are no considerable differences in average or median IWAs across farm sizes. The cognitive variables, such as farming experience and information access, have a tendency to increase with farm sizes, while education does not show such a tendency (see rows associated with "cognitive variables" in table 3). The socioeconomic variables, such as equipment and services, income source, distance to plots and family size, except for gender show an upward trend as the farm size increases (see rows associated with "socioeconomic variables" in table 3). Overall, the summary statistics demonstrate that farmers are homogeneous in relation to education and IWA, while they are heterogeneous in relation to AdaptNum, AdaptInd, CPInd, farming experience, information access, equipment and services, income source, distance to plots, family size and gender.

Table 4 reports the estimated coefficients, marginal effects and their respective standard errors of the independent variables on AdaptNum in Poisson regression models. The results underscore the robustness of the key variables across all four regression models, characterizing the relationships with AdaptNum. For instance, the marginal effects of the medium and small-size farms on AdaptNum are negative and statistically significant at 1 % level across all models. The results demonstrate that medium and small-size farms do not adapt as compared to large-size farms. The cognitive variables, such as CPInd, farming experience and information access, show positive relationships with AdaptNum, aligning with existing literature (Islam et al., 2016, Dang et al., 2019, Ajani and Geest, 2021, Fischer et al., 2022, Ewalo and Vedeld, 2023). We also observe that socioeconomic variables, such as IWA, equipment and services, income source, distance to plots and family size, are significant. Past studies suggest that IWA is crucial in semiarid and arid regions (Sorg et al., 2014, Ndamani and Watanabe, 2015, Golla, 2021, Sharofiddinov et al., 2024), and equipment and extension services play vital roles in agricultural production and farmers' adaptations (Fahad and Wang, 2018, Umunakwe et al., 2022). Interaction terms between farm-sizes and

Table 4: Estimated coefficients of the independent variables on the number of adaptations (AdaptNum) in the Poisson regressions

	Model 1		Model 2		Model 3		Model 4	
	Coefficient	ME	Coefficient	ME	Coefficient	ME	Coefficient	ME
Farm-size variables								
Farm-size dummies								
(base group = Large-size farm)								
Medium-size farm	−0.17***	−1.31***	−0.13***	−0.96***	−0.11***	−0.86***	−0.27	−1.14***
	(0.03)	(0.21)	(0.03)	(0.21)	(0.03)	(0.26)	(0.19)	(0.27)
Small-size farm	−0.34***	−2.43***	−0.26***	−1.87***	−0.23***	−1.64***	−0.86***	−1.83***
	(0.04)	(0.27)	(0.04)	(0.27)	(0.05)	(0.34)	(0.26)	(0.35)
Cognitive variables								
Climatic perception index (CPInd)			0.05***	0.33***	0.04***	0.31***	0.03*	0.27***
			(0.01)	(0.06)	(0.01)	(0.06)	(0.01)	(0.06)
Farming experience			0.04***	0.32***	0.03***	0.25***	0.04***	0.27***
			(0.01)	(0.08)	(0.01)	(0.09)	(0.01)	(0.09)
Information access			0.01**	0.09***	0.01**	0.07***	0.01**	0.08**
			(0.01)	(0.03)	(0.005)	(0.03)	(0.005)	(0.03)
Education			−0.01	0.03	0.002	0.01	0.01	0.05
			(0.02)	(0.11)	(0.02)	(0.13)	(0.02)	(0.13)
Socioeconomic variables								
Irrigation water availability (IWA)					0.04***	0.33***	0.03	0.37***
					(0.01)	(0.10)	(0.02)	(0.11)
Equipment and services					0.03***	0.24***	0.04***	0.26***
					(0.01)	(0.08)	(0.01)	(0.08)
Income source (base group = not agriculture)					0.03	0.23	0.06*	0.47*
					(0.03)	(0.25)	(0.03)	(0.26)
Distance to plots					−0.02***	−0.14***	−0.02***	−0.11***
					(0.01)	(0.04)	(0.01)	(0.04)
Family size					0.01***	0.06***	0.01***	0.06***
					(0.002)	(0.02)	(0.003)	(0.02)
Gender (base group = male)					0.01	0.04	−0.001	−0.01
					(0.04)	(0.24)	(0.04)	(0.27)
Interaction terms								
(base group = Large-size farm)								
Medium-size farm × CPInd							0.01	
							(0.02)	
Small-size farm × CPInd							0.03	
							(0.02)	
Medium-size farm × IWA							0.01	
							(0.03)	
Small-size farm × IWA							0.11**	
							(0.05)	
Constant	2.13***		1.47***		1.21***		1.40***	
Sample size	792		771		742		742	
Climatic zones	No		No		No		Yes	
Likelihood-Ratio	79.92***		138.68***		180.09***		204.33***	

*** significant at 1 % level
** significant at 5 % level
* significant at 10 % level
Standard errors are in parentheses

IWA are found to indicate the heterogeneous effects on AdaptNum, implying that AdaptNum by small-size (medium- or large-size) farms is sensitive (insensitive) to IWA with a positive association.

Table 5 reports the estimated coefficients, their corresponding standard errors and the statistical significance level of the independent variables on AdaptInd in median regression models. The details of the median regression results for AdaptInd shall be discussed and interpreted as compared to those for AdaptNum, because the AdaptInd is argued to be one of the most appropriate and credible measurements for farmers' adaptations in literature (Below et al., 2012, Koirala et al., 2022). The estimated coefficients of medium-size farms on AdaptInd are statistically significant with a negative sign in models 1, 2 and 3 at 1 % level. Likewise, the estimated coefficients of small-size farms on AdaptInd are statistically significant at the 1 % level with negative sign across all models. The results indicate that medium- and small-size farms tend not to adapt by $0.52 \sim 0.96$ and by $0.78 \sim 4.52$ on the median AdaptInd, respectively, as compared to large-size farms, holding other variables constant. Overall, the findings suggest that both medium and small-size farms tend not to implement adaptations by the index as compared to large-size farms.

The coefficients of some cognitive variables, such as CPInd, farming experience, information access and education, are statistically significant at 1 % to 10 % level at least in some models (table 5). The results reveal that farmers tend to increase AdaptInd by $0.12 \sim 0.15$ when their CPInd increases by one unit. Previous studies find that CPInd plays an important role in farmers' adaptation responses (Deressa et al., 2011, Abid et al., 2016, Koirala et al., 2022), being consistent with the result. A year of farming experience tend to induce farmers to raise AdaptInd by $0.11 \sim 0.17$ AdaptInd, and it is in line with previous studies that show the positive impact on adaptation decisions (Fadina and Barjolle, 2018, Ado et al., 2020). Farmers are found to decrease AdaptInd by $0.17 \sim 0.21$ as their education level increases by one unit. The negative relationship is not surprising in Tajikistan in that most educated farmers have alternative occupations, inducing themselves to take adaptations from nonagricultural income-generating activities. Other key socioeconomic variables, such as income source and family size, are identified to be significant in some models,

Table 5: Estimated coefficients of the independent variables on the adaptation index (AdaptInd) in the median regressions

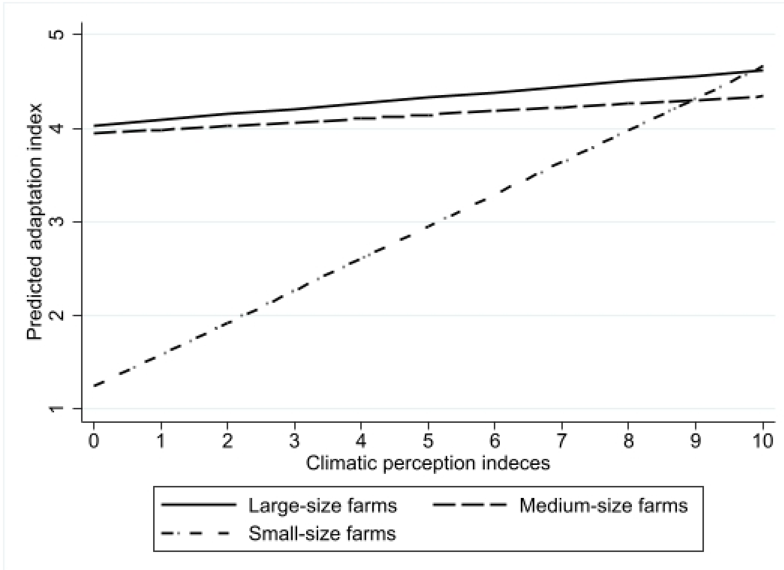
	Adaptation index (AdaptInd)			
	Model 1	Model 2	Model 3	Model 4
Farm-size variables				
Farm-size dummies				
(base group = Large-size farm)				
Medium-size farm	−0.96***	−0.65***	−0.52***	−0.11
	(0.18)	(0.20)	(0.19)	(1.01)
Small-size farm	−1.17***	−0.89***	−0.78***	−4.52***
	(0.24)	(0.26)	(0.26)	(1.27)
Cognitive variables				
Climatic perception index (CPInd)		0.15***	0.12***	0.06
		(0.05)	(0.04)	(0.08)
Farming experience		0.17**	0.13*	0.11*
		(0.07)	(0.07)	(0.06)
Information access		0.05*	0.03	0.02
		(0.03)	(0.03)	(0.03)
Education		−0.21**	−0.17*	−0.09
		(0.11)	(0.10)	(0.09)
Socioeconomic variables				
Irrigation water availability (IWA)			0.06	0.02
			(0.08)	(0.11)
Equipment and services			0.08	0.06
			(0.06)	(0.06)
Income source (base group = not agriculture)			0.36*	0.12
			(0.19)	(0.18)
Distance to plots			−0.04	−0.04
			(0.04)	(0.03)
Family size			0.04**	0.04**
			(0.02)	(0.02)
Gender (base group = male)			0.14	0.10
			(0.20)	(0.19)
Interaction terms				
(base group = Large-size farm)				
Medium-size farm × CPInd				−0.19
				(0.09)
Small-size farm × CPInd				0.28**
				(0.11)
Medium-size farm × IWA				0.01
				(0.15)
Small-size farm × IWA				0.51**
				(0.24)
Constant	4.97***	3.02***	2.36***	2.76***
Sample size	785	766	737	737
Climatic zones	No	No	No	Yes
Pseudo R-squared	0.04	0.06	0.08	0.08

*** significant at 1 % level
** significant at 5 % level
* significant at 10 % level
Standard errors are in parentheses

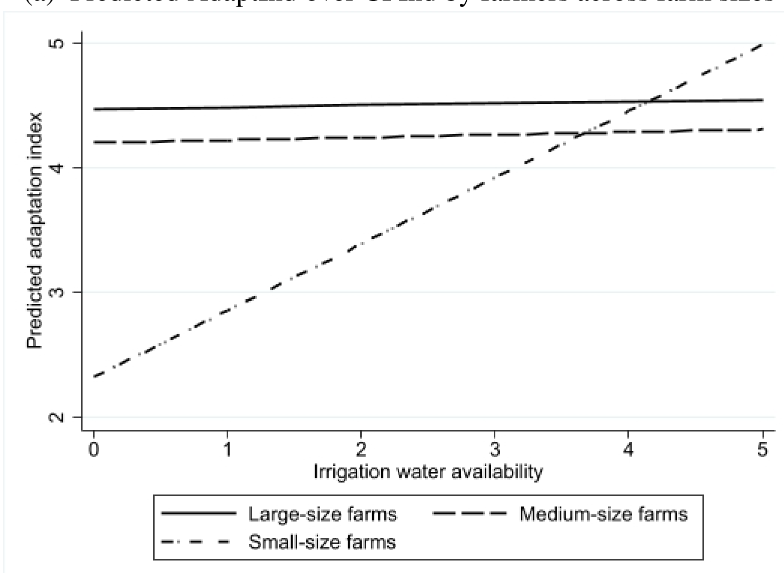
following our expectations and intuitions. The two factors appear to contribute to farms' adaptation capacities, facilitating active engagement for adaptations (Assefa and Gebrehiwot, 2023).

We examine the interaction effects between farm-sizes and CPInd as well as between farm-sizes and IWA on AdaptInd. To this end, the interaction terms are included and estimated in Model 4, enabling us to derive the predicted median AdaptInd over CPInd or over IWA for each farm size. Model 4 shows that the coefficient of the interaction terms between small-size farms and CPInd is statistically significant at 5 % level. It implies that small-size farms tend to raise AdaptInd by 0.34 ($= 0.06 + 0.28$), when their CPInd rises by one unit. Similarly, the coefficient of the interaction terms between small-size farms and IWA is statistically significant at 5 % level, implying that small-size farms take additional AdaptInd by 0.53 ($= 0.02 + 0.51$), when their IWA improves by one level. Overall, adaptations by small-size farms can be interpreted to be highly dependent on CPInd as well as on IWA with positive associations, while large-size and medium-size farms are not. The results suggest some possibility that the interaction effects of farm sizes with CPInd and with IWA practically influence AdaptInd in Tajikistan farming.

Based on the estimation results from model 4, we compute and graph the predicted median AdaptInd over CPInd and IWA for each farm size in consideration to the interactions (figure 5). The predicted median AdaptInd for each of large, medium and small-size farms in figure 5a demonstrates that the intercepts and slopes are idiosyncratic between small-size farms and other-size ones (medium- and large-size farms). In particular, the intercepts for the large and medium-size farms are higher than that for the small-size farms, and the predicted median AdaptInd has a upward slope over CPInd only for small-size farms. On the other hand, it is evident that the predicted median AdaptInd is not sensitive to CPInd for each of medium and large-size farms, being practically flat. Likewise, the same tendencies of the predicted median AdaptInd over IWA are found across farm sizes (figure 5b), presenting that adaptations by small-size (large and medium-size) farms are sensitive (insensitive) to IWA with a positive slope. Overall, figures 5a and 5b are interpreted to suggest that small-size farms in Tajikistan are vulnerable to or fragile against climate change through a decline in adaptations, especially when they have neither proper climate perceptions nor



(a) Predicted AdaptInd over CPInd by farmers across farm sizes



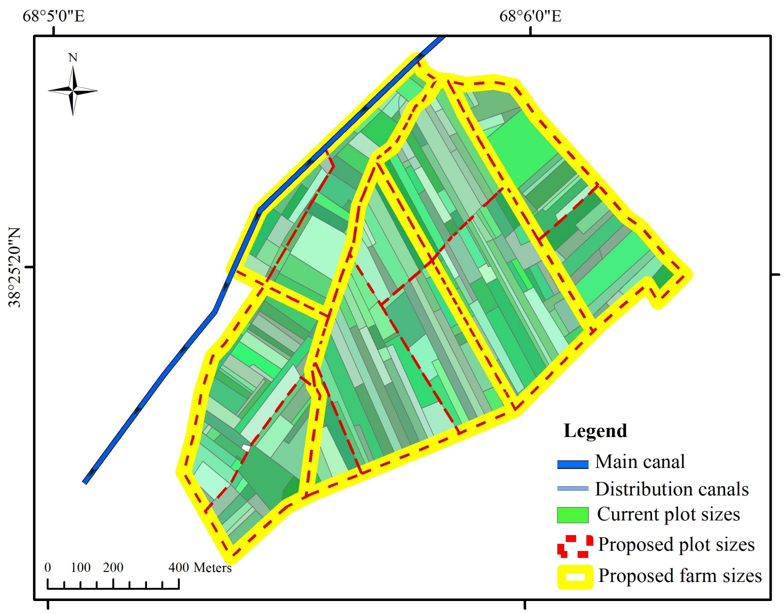
(b) Predicted AdaptInd over IWA by farmers across farm sizes

Figure 5: Predicted adaptation indices (AdaptInd) over climatic perception index (CPInd) and irrigation water availability by farmers across farm sizes

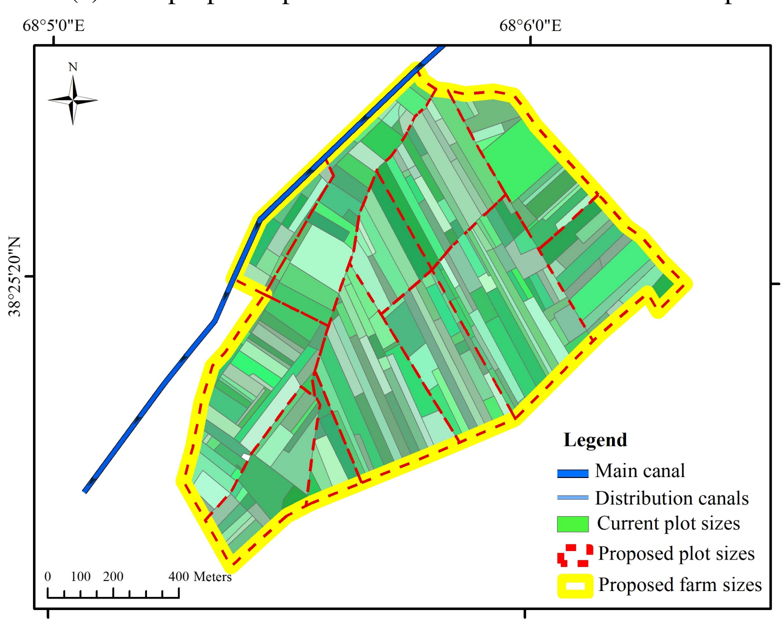
sufficient water availability. It must be noted that large- and medium-size farms do not display such a tendency, and we conjecture that they possess some advantages for adaptations reflecting farming culture and history that have prevailed in Tajikistan as compared to small-size one.

We summarize the statistical and econometric results related to AdaptNum and AdaptInd, providing the answers to our research question and hypothesis. As outlined in our conceptual framework, AdaptNum and AdaptInd are influenced by cognitive factors, socioeconomic ones and their interactions. The results demonstrate that farm sizes, CPInd, farming experience, information access, IWA and family size influence both AdaptNum and AdaptInd in a robust manner. In particular, the summary statistics, boxplots and regression results uniformly suggest that farm sizes are key variables to characterize adaptations, that is, adaptations tend to increase with farm sizes. Estimated coefficients on the interaction terms and the associated graphs show that large and medium-size farms stably take adaptations, irrespective of CPInd and IWA, while small-size farms are sensitive to the factors or vulnerable against climate change. It means that small-size farms go through a decline in adaptations or do not have an ability to adapt, especially when they do not have good CPInd or sufficient IWA. The results may be due to traditional farming practices during the Soviet period "Kolkhoz" and "Sovkhoz" where Tajikistan farmers are familiar with agricultural production and management under large and medium-size farms, adapting to climate change. On the other hand, Tajikistan farmers in small-size farms are known to suddenly become the owners of newly allocated small agricultural plots, and they do not receive proper instructions or training regarding how to manage and make productions under small farming (Van-Assche et al., 2013, Shtaltovna, 2016). Therefore, such farmers may not posses any embodied knowledge, skills and abilities to adapt particularly under the lack of their climate perceptions and water availability. It is our belief that the statistical analyses present coherent results with one another, well reflecting what is going on farmers' adaptations by farm sizes in Tajikistan.

Land fragmentation is a growing worldwide trend which is known to be influenced by external factors, such as population growth, economic uncertainties and policies, bringing farm sizes to be small over time (Tan et al., 2006, Hartvigsen, 2014, Sharofiddinov et al., 2024). In some coun-



(a) The proposed plot and farm sizes in intermediate step



(b) The proposed plot and farm sizes in final step

Figure 6: Proposed plot and farm sizes in intermediate and final steps of land consolidation.

tries, land fragmentation is empirically established to be beneficial as well as to increase farmers' adaptation capabilities in agriculture (Kabubo-Mariara and Mulwa, 2019, Ntihinyurwa et al., 2019, Koirala et al., 2022). In general, however, the superiority between large and small sizes or between large-scale and small-scale business operations is not clear-cut in terms of profitability and adaptation capability, remaining inconclusive depending on the types of management practices, cultural contexts and histories (Revilla and Fernández, 2012, Hollender et al., 2017). Against this background, our research indicates that land consolidation is recommended to enhance agricultural adaptations in Tajikistan and other countries who face the similar situations of old infrastructures and poor water availability due to the cultures and histories. For instance, it shall be effective to establish community-based management, such as enterprises or shareholders, through consolidating small-size farms and their fragmented plots. Figures 6a and 6b depict two examples for possible steps. Figure 6a suggests that approximately 80 medium and small-size farms in 120 ha with 237 plots can be consolidated to form five enterprises (shareholders) that consist of 12 plots on the basis of the plot structures in the pre-reform periods. Figure 6b further suggests that the five enterprises can be merged into one in 120 ha with 12 plots. The suggestions are expected to enable farmers to (i) rotate and diversify their crops, (ii) have access to water irrigation systems and roads, (iii) increase water availability, (iv) improve efficiency of machinery and (v) reduce unnecessarily roads, ditches and farm boundaries under the current water infrastructures in Tajikistan. Alternatively, if such land consolidation is considered unfeasible, small-size farms should receive proper instructions for climate perceptions or further provision of suitable irrigation infrastructures for sufficient IWAs, increasing their adaptations.

5 Conclusion

This study has examined how farm sizes influence adaptation responses in relation to irrigation-related, cognitive and socioeconomic factors reflecting farming culture and history, hypothesizing that large-size farms adapt to climate change as compared to small-size ones in Tajikistan. We utilize a questionnaire survey with 800 farmers on their adaptation responses, farm sizes, climatic perceptions, irrigation water availability (IWA), cognitive and socioeconomic factors. The analyses reveal that farm sizes, climatic perceptions and IWA are key determinants to characterize adaptations. The findings show that small-size farms do not adapt as compared to medium- and large-size farms, and the adaptations by small-size farms are highly dependent on their climatic perceptions and IWA. Overall, this research establishes that large and medium-size farms take adaptations irrespective of climatic perceptions and IWA, while small-size farms are found to be sensitive to or vulnerable against climate change. Therefore, the results indicate that the ongoing land-fragmentation policy in Tajikistan should be reconsidered due to the losses in adaptation responses, as it has been drastically increasing the number of small-size farms. Otherwise, it is crucial to provide proper guidance for how to manage and adapt through improving small-size farmers' climatic perceptions and developing proper irrigation infrastructures to ensure their water availability.

We acknowledge some limitations of this study and provide directions for future research. Our analyses do not incorporate long-term farmers' adaptations in relation to climatic data. Our study captures farm-level adaptations including their quantity and coverage areas in relation to various factors and farm sizes with the cross-sectional data. Farmers' adaptations may go beyond the results by analyzing the cross sectional data through a questionnaire survey. Thus, future studies should collect panel data that include farmers' adaptations and climatic data over several growing seasons or years. By doing so, further countermeasures for increasing agricultural adaptations shall be identified. Moreover, we do not associate farmers' adaptations with their performances, such as profits or productions in the analyses. In future, it is recommended to examine the relation between some performance variables and adaptations in relation to farm sizes within a single framework, utilizing switching regressions. This type of researches shall contribute to our understanding of how the sizes matter for not only adaptations but also performances along with the relation between the two. Despite the limitations, we believe that this study demonstrates a clear evidence, that is, farm sizes are keys for adaptations and land fragmentation is not necessarily recommended in the context of Tajikistan. The evidence shall be considered an important initial step for clarifying the functions among farm sizes, cognitive and socioeconomic factors in agriculture as well as for countering adverse effects from climate change on food security in countries facing the same types of situations as in Tajikistan.

Acknowledgement: We would like to thank the anonymous reviewers, Makoto Kakinaka, Sulton Rahimzoda, Kostya Ovsiannikov, Khatun Asma, Mostafizur Rahman and Mirzoqurbon Pochoev for the helpful comments and support. The authors specially thank the Ministry of Energy and Water Resources, the Agency for Land Reclamation and Irrigation and Agency of civil service under the President of the Republic of Tajikistan for their support. We are also grateful for the financial support from the Japanese Society of Promotion of the Science as the Grant-in- Aid for Scientific Research B (19H01485), Research Institute for Future Design, Kochi University of Technology and the Project for Human Resource Development Scholarship by Japanese Grant Aid (JDS).

References

Abid, M., Schneider, U., and Scheffran, J. (2016). Adaptation to climate change and its impacts on food productivity and crop income: Perspectives of farmers in rural Pakistan. *Journal of rural studies*, 47:254–266.

Acquah, D. (2011). Farmers perception and adaptation to climate change: A willingness to pay analysis. *Journal of sustainable development in Africa*, 13:150–161.

Ado, M., Savadogo, P., Pervez, K., and Mudimu, T. (2020). Farmers' perceptions and adaptation strategies to climate risks and their determinants: Insights from a farming community of Aguie district in Niger. *GeoJournal*, 85:1075–1095.

Ajani, A. and Geest, K. (2021). Climate change in rural Pakistan: Evidence and experiences from a people-centered perspective. *Sustainability science*, 16:1999–2011.

Alauddin, M. and Sarker, R. (2014). Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh: An empirical investigation. *Ecological economics*, 106:204–213.

Ali, A. and 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.

Alimov, D. (2020). Construction of water management infrastructure and development of new lands in the southern regions of Tajikistan (1920-1980). *disserCat*, pages 1–400.

ALRI (2020). Annual reports from 1996 to 2020. Technical report, Agency for Land Reclamation and Irrigation under the government of the Republic of Tajikistan.

Amare, A. and Simane, B. (2017). Determinants of smallholder farmers' decision to adopt adaptation options to climate change and variability in the Muger sub basin of the Upper Blue Nile basin of Ethiopia. *Agriculture and food security*, 6:64.

Ardakani, Z., Bartolini, F., and Brunori, G. (2020). New evaluation of small farms: Implication for an analysis of food security. *Agriculture*, 10:74.

Arnalte-Mur, L., Ortiz-Miranda, D., Cerrada-Serra, P., Martinez-Gómez, V., Moreno-Pérez, O., Barbu, R., Bjorkhaug, H., Czekaj, M., Duckett, D., Galli, F., Goussios, G., Grivins, M., Hernandez, P., Prosperi, P., and Sumane, S. (2020). The drivers of change for the contribution of small farms to regional food security in Europe. *Global food security*, 26:100395.

Assefa, E. and Gebrehiwot, G. (2023). Gender dimensions of climate change adaptation in Tigray, Ethiopia. *Global environmental change*, 82:102737.

Bakhsh, K. and Kamran, A. (2019). Adaptation to climate change in rain-fed farming system in Punjab, Pakistan. *International journal of the commons*, 13:833–847.

Belay, A., Recha, J., Woldeamanuel, T., and Morton, J. (2017). Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. *Agriculture and food security*, 6:24.

Below, T., Mutabazi, K., Kirschke, D., Franke, C., Sieber, S., Siebert, R., and Tscherning, K. (2012). Can farmers' adaptation to climate change be explained by socio-economic household-level variables? *Global environmental change*, 22:223–235.

Bobojonov, I. and Aw-Hassan, A. (2014). Impacts of climate change on farm income security in Central Asia: An integrated modeling approach. *Agriculture, ecosystems and environment*, 188:245–255.

Burkel, M. and Lobell, D. (2010). Food security and adaptation to climate change: What do we know? *Climate change and food security: Adapting agriculture to a warmer world*, 37:133–153.

Campbell, B., Vermeulen, S., Aggarwal, P., Corner-Dolloff, C., Girvetz, E., Loboguerrero, M., Ramirez-Villegas, J., Rosenstock, T., Sebastian, L., Thornton, P., and Wollenberg, E. (2016). Reducing risks to food security from climate change. *Global food security*, 11:34–43.

Conover, W. and Iman, R. (1981). Rank transformations as a bridge between parametric and nonparametric statistics. *American statistician*, 35:124–129.

Corder, G. and Foreman, D. (2014). *Nonparametric statistics: A step-by-step approach*. John wiley and sons, second edition edition.

Dang, L., Li, E., Nuberg, I., and Bruwer, J. (2019). Factors influencing the adaptation of farmers in response to climate change: A review. *Climate and development*, 11:765–774.

Datta, P., Behera, B., and Rahut, D. (2022). Climate change and Indian agriculture: A systematic review of farmers' perception, adaptation, and transformation. *Environmental challenges*, 8:100543.

Deressa, T., Hassan, R., and Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *Journal of agricultural science*, 149:23–31.

Din, S., Mubeen, M., Hussain, S., Ahmad, A., Hussain, N., Ali, A., Sabagh, A., Elsabagh, M., Shah, M., Qaisrani, A., Tahir, M., Javeed, H., Anwar, M., Ali, M., and Nasim, W. (2022). World nations priorities on climate change and food security. In *Building climate resilience in agriculture: Theory, practice and future perspective*, pages 365–384. Springer.

Dixon, J., Stringer, L., and Challinor, A. (2014). Farming system evolution and adaptive capacity: Insights for adaptation support. *Resources*, 3:182–214.

Esham, M. and Garforth, C. (2013). Agricultural adaptation to climate change: Insights from a farming community in Sri Lanka. *Mitigation and adaptation strategies for global change*, 18:535–549.

Ewalo, W. and Vedeld, P. (2023). Climate change in the Sidama region, Ethiopia: Linking perceptions and adaptation. *GeoJournal*, 88:1–19.

Fadina, R. and Barjolle, D. (2018). Farmers' adaptation strategies to climate change and their implications in the Zou department of South Benin. *Environments*, 5:15.

Fahad, S. and Wang, J. (2018). Farmers' risk perception, vulnerability, and adaptation to climate change in rural Pakistan. *Land use policy*, 79:301–309.

Fischer, A., Russo, M., and Powers, G. (2022). Behavioral adaptation to climate change: New insights on psychosocial frameworks from the context of managed forests. *Sustainability science*, 17:1023–1036.

Fujimori, S., Hasegawa, T., Rogelj, J., Su, X., Havlik, P., Krey, V., Takahashi, K., and Riahi, K. (2018). Inclusive climate change mitigation and food security policy under 1.5 C climate goal. *Environmental research letters*, 13:074033.

Golla, B. (2021). Agricultural production system in arid and semi-arid regions. *International journal of agricultural science food technology*, 7:234–244.

Grothmann, T. and Patt, A. (2005). Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Global environmental change*, 15:199–213.

Gulakhmadov, A., Chen, X., Gulahmadov, N., Liu, T., Davlyatov, R., Sharofiddinov, S., and Gulakhmadov, M. (2020). Long-term hydro–climatic trends in the mountainous Kofarnihon river basin in Central Asia. *Water*, 12:2140.

Hanjra, M. and Qureshi, E. (2010). Global water crisis and future food security in an era of climate change. *Food policy*, 35:365–377.

Hartvigsen, M. (2014). Land reform and land fragmentation in Central and Eastern Europe. *Land use policy*, 36:330–341.

Hirose, J., Kotani, K., and Managi, S. (2023). Do autonomy and inquisitiveness contribute to SDGs? Implications from the matrilineal island of Palau. *Economic analysis and policy*, 79:303–318.

Hollender, L., Zapkau, F., and Schwens, C. (2017). SME foreign market entry mode choice and foreign venture performance: The moderating effect of international experience and product adaptation. *International business review*, 26:250–263.

Huttunen, S., Mela, H., and Hildén, M. (2015). Good farmers, good adapters? How cultural understanding of good farming affects the adaptive capacity of farmers. In Paloviita, A. and Järvelä, M., editors, *Climate change adaptation and food supply chain management*, pages 107–118. Routledge, Oxon OX14.

Islam, M., Kotani, K., and Managi, S. (2016). Climate perception and flood mitigation cooperation: A Bangladesh case study. *Economic analysis and policy*, 49:117–133.

Jensen, S. and Traeger, C. (2014). Optimal climate change mitigation under long-term growth uncertainty: Stochastic integrated assessment and analytic findings. *European economic review*, 69:104–125.

Jha, C. and Gupta, V. (2021). Farmer's perception and factors determining the adaptation decisions to cope with climate change: An evidence from rural India. *Environmental and sustainability indicators*, 10:100112.

Kabubo-Mariara, J. and Mulwa, R. (2019). Adaptation to climate change and climate variability and its implications for household food security in Kenya. *Food security*, 11:1289–1304.

Khan, I., Lei, H., Shah, I., Ali, I., Khan, I., Muhammad, I., Huo, X., and Javed, T. (2020). Farm households' risk perception, attitude and adaptation strategies in dealing with climate change: Promise and perils from rural Pakistan. *Land use policy*, 91:104395.

Khatun, N. (2021). Applications of normality test in statistical analysis. *Open journal of statistics*, 11:113.

Koirala, P., Kotani, K., and Managi, S. (2022). How do farm size and perceptions matter for farmers' adaptation responses to climate change in a developing country? Evidence from Nepal. *Economic analysis and policy*, 74:188–204.

Li, T., Qi, Y., Chen, M., and Cao, J. (2023a). Balancing crop security and sustainable cropland use: Policy lessons from the watershed ecosystem service payments in Xin'an River, China. *Economic analysis and policy*, 80:861–879.

Li, Y., Zhang, Z., Liu, S., Cao, Z., Ke, Q., Chen, L., and Wang, G. (2023b). Long-term responses in different karst agricultural production systems to farm management and climate change: A comparative prefecture-scale study in Southwest China. *Agriculture, ecosystems and environment*, 352:108504.

Linnenluecke, M., Birt, J., and Griffiths, A. (2015). The role of accounting in supporting adaptation to climate change. *Accounting and finance*, 55:607–625.

Mahato, A. (2014). Climate change and its impact on agriculture. *International journal of scientific and research publications*, 4:1–6.

Mandryk, M., Reidsma, P., Kanellopoulos, A., Groot, J., and Ittersum, M. (2014). The role of farmers' objectives in current farm practices and adaptation preferences: A case study in Flevoland, the Netherlands. *Regional environmental change*, 14:1463–1478.

Marie, M., Yirga, F., Haile, M., and Tquabo, F. (2020). Farmers' choices and factors affecting adoption of climate change adaptation strategies: Evidence from northwestern Ethiopia. *Heliyon*, 6:e03867.

Maya, K., Sarker, A., and Gow, J. (2019). Factors influencing rice farmers' adaptation strategies to climate change and extreme weather event impacts in Bangladesh. *Climate change economics*, 10:1950012.

MEDT (2013). *National development strategy of the Republic of Tajikistan for the period up to 2030*. Ministry of Economic Development and Trade of the Republic of Tajikistan. Retrived from `https://medt.tj/en/strategy-and-programes/nds2030`. Last checked on November 27, 2023.

Moore, F., Baldos, L., and Hertel, T. (2017). Economic impacts of climate change on agriculture: A comparison of process-based and statistical yield models. *Environmental research letters*, 12:065008.

Nabikolo, D., Bashaasha, B., Mangheni, M., and Majaliwa, J. (2012). Determinants of climate change adaptation among male and female headed farm households in eastern Uganda. *African crop science journal*, 20:203–212.

Ndamani, F. and Watanabe, T. (2015). Farmers' perceptions about adaptation practices to climate change and barriers to adaptation: A micro-level study in Ghana. *Water*, 7:4593–4604.

Nelson, G. and van der Mensbrugghe, D. (2014). Public-sector agricultural research priorities for sustainable food security: Perspectives from plausible scenarios. In *How does climate change alter agricultural strategies to support food security?*, International Food Policy Research Institute: IFPRI Discussion Paper 01339.

Normatov, I., Azimov, D., and Sharofzoda, F. (2023). Spatial distribution of precipitation and its contribution to the formation of the transboundary Zeravshan river runoff (Tajikistan). *Russian meteorology and hydrology*, 48:682–686.

Ntihinyurwa, P., Vries, W., Chigbu, U., and Dukwiyimpuhwe, P. (2019). The positive impacts of farm land fragmentation in Rwanda. *Land use policy*, 81:565–581.

Ojo, T. and Baiyegunhi, L. (2020). Determinants of climate change adaptation strategies and its impact on the net farm income of rice farmers in south-west Nigeria. *Land use policy*, 95:103946.

Orchard, S., Glover, D., Thapa, S., Ayele, S., Sen, D., Rathod, R., and Rowhani, P. (2020). Exploring synergies and trade-offs among the sustainable development goals: Collective action and adaptive capacity in marginal mountainous areas of India. *Sustainability science*, 15:1665–1681.

Rasul, G. and Sharma, B. (2016). The nexus approach to water-energy-food security: An option for adaptation to climate change. *Climate policy*, 16:682–702.

Revilla, A. and Fernández, Z. (2012). The relation between firm size and R&D productivity in different technological regimes. *Technovation*, 32:609–623.

Rogers, R. (1983). Cognitive and physiological processes in fear appeals and attitude change: A revised theory of protection motivation. In *Social psychology: A source book*, pages 153–176. Guilford Press.

Rogers, R. and Prentice-Dunn, S. (1997). Protection motivation theory. In *Handbook of health behavior research 1: Personal and social determinants*. Plenum Press.

Rosegrant, M. and Cline, S. (2003). Global food security: Challenges and policies. *Science*, 302:1917–1919.

Rowe, W. (2010). Agrarian adaptations in Tajikistan: Land reform, water and law. *Central asian survey*, 29:189–204.

Sandilya, J. and Goswami, K. (2024). Effect of different forms of capital on the adoption of multiple climate-smart agriculture strategies by smallholder farmers in Assam, India. *Mitigation and adaptation strategies for global change*, 29:30.

Sarker, R., Alam, K., and Gow, J. (2012). Exploring the relationship between climate change and rice yield in Bangladesh: An analysis of time series data. *Agricultural systems*, 112:11–16.

Sasson, A. (2012). Food security for Africa: an urgent global challenge. *Agriculture and food security*, 1:1–16.

SCLMG (2020). Annual reports from 1996 to 2020. Technical report, State Committee on Land Management and Geodesy, Tajikistan.

Shapiro, S. and Wilk, M. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, 52:591–611.

Sharofiddinov, H., Islam, M., and Kotani, K. (2024). How does the number of water users in a land reform matter for water availability in agriculture? *Agricultural water management*, 293:108677.

Shtaltovna, A. (2016). Knowledge gaps and rural development in Tajikistan: Agricultural advisory services as a panacea? *Journal of agricultural education and extension*, 22:25–41.

Solano, C., León, H., Pérez, E., and Herrero, M. (2001). Characterising objective profiles of Costa Rican dairy farmers. *Agricultural systems*, 67:153–179.

Sorg, A., Mosello, B., Shalpykova, G., Allan, A., Clarvis, H., and Stoffel, M. (2014). Coping with changing water resources: The case of the Syr Darya river basin in Central Asia. *Environmental science and policy*, 43:68–77.

Sotnikov, V. (1960). Farming problems in the zones of the USSR and the tasks of Soviet geographers. *Soviet geography*, 1:3–22.

Sulaymonshoev, M. (2011). Historical experience of formation and development the state agricultural enterprises in Tajikistan (1924-1941). *disserCat*, pages 1–164.

Sun, J., Tao, R., Wang, J., Wang, Y., and Li, J. (2024). Do farmers always choose agricultural insurance against climate change risks? *Economic analysis and policy*, 81:617–628.

Tan, S., Heerink, N., and Qu, F. (2006). Land fragmentation and its driving forces in China. *Land use policy*, 23:272–285.

Tesfaye, W. and 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*, 8:253–270.

Thinda, K., Ogundeji, A., Belle, J., and Ojo, T. (2020). Understanding the adoption of climate change adaptation strategies among smallholder farmers: Evidence from land reform beneficiaries in South Africa. *Land use policy*, 99:104858.

Trinh, Q., Ranola, R., Camacho, L., and Simelton, E. (2018). Determinants of farmers' adaptation to climate change in agricultural production in the central region of Vietnam. *Land use policy*, 70:224–231.

Uddin, N., Bokelmann, W., and Entsminger, S. (2014). Factors affecting farmers' adaptation strategies to environmental degradation and climate change effects: A farm level study in Bangladesh. *Climate*, 2:223–241.

Umunakwe, P., Madukwe, M., and Aja, O. (2022). Capabilities of agriculturalextension personnel to transfer climate adaptation technologies to farmers in Imo State, Nigeria. *Ife journal of agriculture*, 34:43–56.

Van-Assche, K., Hornidge, A.-K., Shtaltovna, A., and Boboyorov, H. (2013). Epistemic cultures, knowledge cultures and the transition of agricultural expertise: Rural development in Tajikistan, Uzbekistan and Georgia. ZEF working paper series 118, University of Bonn, Center for Development Research (ZEF).

Vinaya, H., Shivamurthy, M., Govinda, V., and Biradar, G. (2017). Assessing decision-making and economic performance of farmers to manage climate-induced crisis in Coastal Karnataka (India). *Climatic change*, 142:143–153.

Wooldridge, J. (2019). *Introductory econometrics: A modern approach*. Cengage learning, seventh edition.

World Bank (2021). *Employment in agriculture*. Retrived from https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS. Last checked on April 24, 2023.

Ziervogel, G. and Ericksen, P. (2010). Adapting to climate change to sustain food security. *Wiley interdisciplinary reviews: Climate change*, 1:525–540.