

# Unlocking the potential of Explainable climate-risk economics for agriculture and water stress in Uzbekistan

Nosurullaev Kodir<sup>1\*</sup>, Tolipova Bakhtigul<sup>2</sup>

<sup>1</sup>Department of Economics. Tashkent institute of irrigation and agricultural mechanization engineers. National research university, 39, Kary Niyazi str., Tashkent, Uzbekistan

<sup>2</sup>Department of HR and personnel development. Nordic International University. 290, Farabi str., Tashkent, Uzbekistan.

**Abstract.** This is a mixed-method research design aimed at investigating the role of explainable climate-risk assessment in agriculture and water management on the resilience outcomes for smallholder farmers among rural farming communities. The main objective of this study is to find out that the development of explainable climate-risk models needs no extra financial burden, but has a great role in improving adaptive decision-making. This study aimed at investigating the impact of a climate-risk prioritization framework on agricultural planning and water allocation in different levels of drought exposure in Uzbekistan. In addition, the AHP analysis showed that irrigation efficiency and crop diversification are the two major adaptation practice priorities that are statistically significant predictors of farm survival probability. The method of the study was quasi-experimental and the intervention action was performed in two treatment groups; conventional risk assessment was employed in one group and in the other group, the same method together with explainable climate-risk dashboards for farmers were employed. The results showed that AHP's weighted index ( $\beta = 0.42$ ,  $p \leq 0.05$ ) significantly improved the farmers' adaptive capacity in drought-prone districts. Results from parametric survival analysis revealed a positive and statistically significant relationship between farmers' risk beliefs and the probability for sustained agricultural productivity among irrigated farms. Overall, the research result can impact policymakers in regional water authorities to review and enhance their risk governance strategies and provide a better understanding of the importance of farmers' risk perception mechanisms toward agriculture's climate resilience that supports sustainable production and efficient water use in Uzbekistan.

**Keywords:** Explainable Climate-Risk Assessment, Agricultural Adaptation, Water Stress Management, Smallholder Farmers, Analytic Hierarchy Process (AHP), Parametric Survival Analysis, Climate Resilience in Uzbekistan.

\* Corresponding author: [q.nosrullayev@tiame.uz](mailto:q.nosrullayev@tiame.uz)

## 1. Introduction

Smallholder farmers are highly vulnerable populations and affected by their surroundings. According to an old saying among farmers found in Central Asia (Uzbekistan) to discover water sources would be the last creatures. Most scholars such as Ward (2021), Mitchell et al. (2017), and Mukhamedjanov et al. (2020) pay attention to both climate variability and water scarcity and their role in agricultural productivity and based on new approaches such as machine learning, decision support systems and explainable analytics are considered as an effective policy tool. Moreover, agricultural leaders tend to help farmers in coping with climate risks and assist them in taking up new adaptation strategies in line with the emerging challenges (Trail & Ward, 2024). Hamidov et al. defines climate resilience as an integrated approach including assessment, planning and management of water resources for adaptation and mitigation methods, governance processes and policy instruments through organizing the newly available scientific knowledge (Hamidov et al., 2020). The greater part of this low climate-risk awareness is spent on reactive coping only and no developmental planning in risk reduction are carried out. However, most of the previous studies have not pointed out how risk perceptions function as the mediating factor in influencing other variables in climate adaptation behavior and usage (Gazzotti et al., 2025; Rebar et al., 2024). The report revealed that farmers' sense of urgency is low among rural communities because of the institutional constraints and the limited resources that have discouraged and constrained them." "This issue of low and slow uptake of climate-risk tools among farmers brings us to one very critical question: What can be done to ensure that farmers do and want to accept and use climate-risk information in carrying out their farming as adaptive planning?" Different researchers have developed studies to understand climate-risk perception and its importance in adaptation effectiveness. Jones and Leibowicz (2021) argue that achieving successful climate adaptation in agriculture will require integrated policies, financial incentives and institutional support. Therefore, the researchers address the following question: Is farmers risk perception the contributory domain towards farmers' adoption of innovations in under-resourced rural communities? The results of studies by Mitchell et al. (as cited by Mukhamedjanov et al., 2020) indicates that: "Farmers that are in groups under participatory learning method in two or several individual groups, support each other and benefit shared knowledge and compared to farmers that get educated with individual and conventional method of extension, have more adoption of the new technologies. The study indicated that the level of farmers' sense of responsibility increased in parallel with the increasing level of climate awareness in communities. Salokhiddinov et al. (2020) and Salokhiddiov et al. (2020) found that despite the availability of irrigation equipment in agriculture and the promise of modern technologies, adoption of innovations consistently showed decline in actual field usage. The literature on climate adaptation studies have discussed the two terms such as risk awareness"and risk perception. Mostly these concepts were used interchangeably but they are not the same thing. Is this the main cause of low level technology usage among farmers? According to Baccour et al. (2025), adopting evidence-based planning standards and adequate training will help agricultural leaders and policymakers to manage water risks effectively in practice. The study aims at examining the influence of risk belief and adaptation

knowledge on resilience outcomes for smallholder farmers in the field of agriculture and water resources. This study aims at investigating the impact of the level of climate-risk assessment practices and adaptive planning in rural secondary agricultural communities. The explainable climate-risk model contributed significantly to the change in criterion on collective adaptive behavior (Gazzotti et al., 2025). Hence, as applied to this study, these theories (transformational and path-goal) hold that the explainable climate-risk practices will enhance performance because very often, the farmers are found to be relating their performance to the perceived usefulness of their decisions. An analysis of a parametric survival model was conducted on a sample of crop-producing farms from the agricultural sector in Uzbekistan. In this study 180 individuals out of farming households in three provinces out of irrigated agricultural regions of fifth administrative divisions from a rural setting in drought-prone areas of Uzbekistan were selected randomly as experimental group and the remaining 60 individuals were made the control group. Thus, this study was carried out to examine the relationship between climate-risk prioritization practices and farmer performance in irrigated secondary agriculture. The results indicated significant differences in farmers adaptive progress between the experimental and control groups and significant increase in learning and productivity progress in the explainable model.

## **2. Methods**

The statistical sample included all selected rural farming households studying irrigated agriculture and water management at community centers of three provinces in Uzbekistan (drought-prone districts). The data were used for determining internal consistency, estimation of reliability, exploratory factor analysis and assessment of predictive validity of adaptation practices in the study. The farming households in irrigated regions of Uzbekistan were considered as the population of this study. In this study 180 subjects were selected from three different provinces and drought-prone districts. Randomly selected villages were visited by the researchers and data were collected from 60 respondents from each sample group. A total of 200 questionnaires were distributed to the participants and a total of 180 questionnaires collected were analyzed, representing a valid response rate of 90%. To determine the sample size for the population, the table of Krejcie and Morgan (1970) was used. According to the table, the minimum size of the sample is 180 out of 320 households.

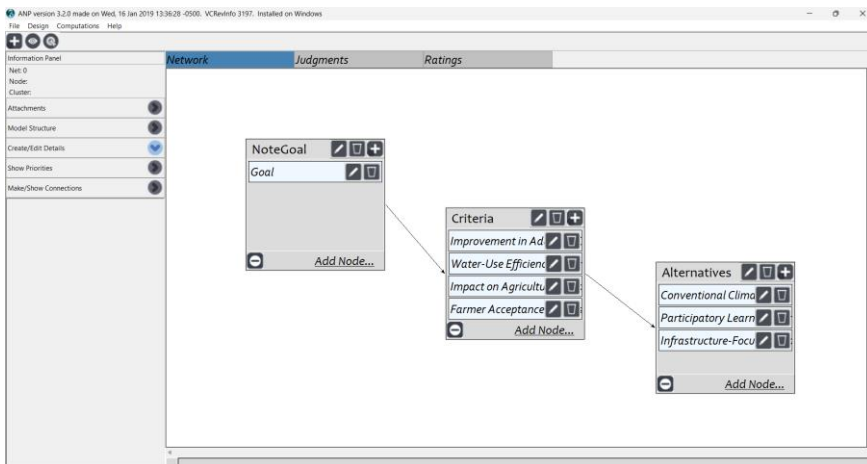
Using the stratified sampling method with proportional allocation to size and location, the sample size was estimated to be 180 individuals. Therefore, purposive sampling is used in this study so that only farmers in the under-resourced rural areas of irrigated agriculture are selected and those who do not suit the research purpose were excluded. Sample selection for this study was conducted in several stages by multistage sampling procedure which included cluster random sampling, simple random sampling, and systematic random sampling. The study was aimed at finding the effects of risk beliefs and adaptation knowledge between climate-risk practices and farm effectiveness. The participants were informed to gather at one location and prior to the administration of the questionnaire, participants were briefed on the purpose of this study, told of their rights to withdraw from the study before, during, or after they had completed the survey and informed that their participation was voluntary and confidentiality was guaranteed to minimize ethical concerns. The research instrument was a structured questionnaire consisting of four types of questions, which were demographic ones,

farmers self-efficacy scale (SES), farmers risk perception scale (RPS), and the level of adaptation practices for drought." The reliability for this instrument using Cronbach's alpha was 0.78 in low levels of knowledge domain and equal to 0.91 in high levels of knowledge domain. Therefore, to determine the reliability of the questionnaire for the main study and other parts (risk perception and adaptation knowledge), a pilot study was conducted on 30 farmers outside of the research sample. The researcher chooses this structured questionnaire because it provides the highest level of measurement precision, allowing all statistical analyses to be performed (descriptive, inferential, regression, & survival analysis, AHP). The data collection is carried out through field survey method. A formal letter was sent to the related local authorities to obtain official permission from the district administration to enter the site and to study their farming practices. After this, the outside intervention part of the experimental plan begins by giving training to the main experimental groups (Group A to B) and it was here that the facilitators with farmers (the strongest members of the community) began acting. The fourth part, which included a 20-item scale with a five-point Likert format (ranging from strongly agree (5) to strongly disagree (1)), measured the attitudes for adaptation. The training was provided to the second experimental group by participatory learning method together with explainable dashboards of climate risk and the information was provided to the farmers in the third group by the conventional method. "Scores over 80 represented high resilience level, while those between 50 and 79 moderate level, and scores under 50 indicated low resilience level (adapted from previous studies). The baseline adaptive capacity and productivity progress scores was distributed among the farmers in the three groups before the beginning of intervention and the performance for each was measured and recorded. The study was aimed at finding the effects of risk beliefs and adaptation knowledge between climate-risk practices and farm effectiveness. The results indicated that this framework is a valid, reliable and useful tool for measuring resilience outcomes and adaptation strategies. The perception scale developed by the researchers had 25 items measured with Likert responses ranging from strongly disagree (1), disagree (2), undecided (3), agree (4), and strongly agree (5). Adaptive capacity was measured according to FAO guidelines (2018). Adaptive capacity is a standard for evaluating the knowledge and skills which farmers need to anticipate, respond and recover in the agricultural world. Table 1 details the test statistics results for validity and reliability for the study. In this study the overall reliability using Cronbach's alpha was determined equal to 0.84 in the dimension of goal beliefs, 0.81 in the dimension of risk perception and interest and equal to 0.88 in the dimension of resilience beliefs. To measure the differences for risk perception and resilience belief among farmers and also to categorize them according to low level (LL), medium level (ML), and high level (HL), the difference between pre-test and post-test scores (gain score) was used as follows after collecting the responses to the items (pre-test, post-test). The classification was developed based on the framework in previous research (Bandura) as guidelines together with the recommendations of some experts related to climate adaptation studies from an instrument named Adaptation Assessment Tool which was developed by FAO (2018, 2020, 2022, & 2023). According to the table of Krejcie and Morgan (1970) the minimum size of the sample is 180 out of 320 households. Scores over 80 represented high resilience level, while those between 50 and 79 moderate level, and scores under 50 indicated low level (adapted from previous studies).

Quantitative data gathered were analyzed quantitatively using AHP and parametric survival models. The reliability for this test using Cronbach's alpha was 0.78 in low levels of knowledge and equal to 0.91 in high levels of knowledge. SPSS software was used for data analysis. The results indicated that this test is a valid, reliable and useful approach for measuring resilience outcomes and adaptation strategies. The face and content validity of the measuring tools were confirmed by gaining the opinions of some faculty members of the departments of agriculture and economics. The developed questionnaire was revised using expert feedback in some pilot sessions in the provinces of Tashkent, Samarkand and Bukhara. The results of analysis showed that the Cronbach alpha values fell between 0.78–0.91 for the adaptation practices scale, and in the range of 0.80–0.88 for resilience beliefs. The results indicated that this instrument is a valid, reliable and useful tool for measuring resilience outcomes and adaptation strategies.

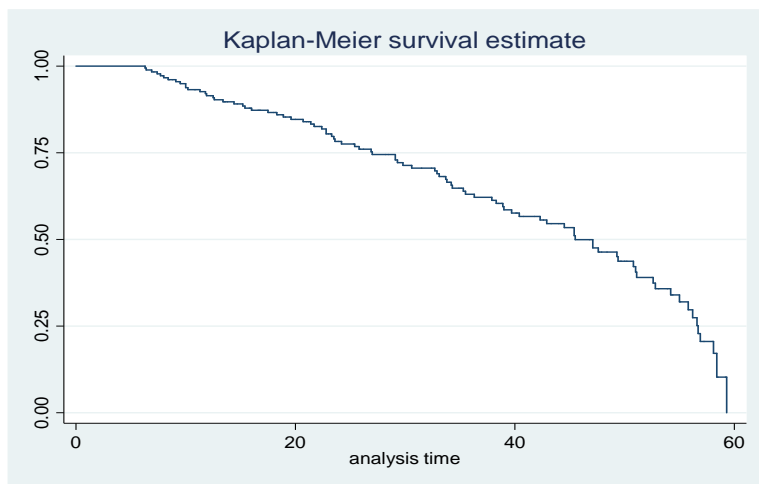
### 3. Results

The results in Table 1 indicate a significant relationship between the risk perception variable and the probability of farmers' farm survival at drought-prone districts. Based on the AHP analysis, the overall priority weight for conventional climate-risk assessment is 0.462073. This could be interpreted as higher level of influence on decision-making outcomes in rural agriculture.



**Fig. 1.** Screenshot of the ANP Model in SuperDecisions Software

The study revealed that risk perception has a significant association with adaptive capacity and this relationship is supported by the p-value of  $\leq 0.05$ . Results indicated a positive and significant relationship between AHP priority scores and farmers' adaptive capacity.



**Fig. 2.** Survival Curve Using Kaplan-Meier Estimator

Table 1 shows the multiple survival analysis that reveals farmers’ risk perception score (Coef. = .991,  $p \leq .1$ ) as a significant predictor of farm survival probability. According to the results of Gompertz regression, the value of risk perception score obtained from the model was significant at the level of  $p \leq .1$ , indicating a meaningful association between the risk perception variable and the survival outcome variable.

**Table 1.** Weibull PH regression

_t	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
age_farmer	.984	.008	-1.86	.063	.968	1.001	*
farm_size_hectares	.998	.027	-0.08	.935	.946	1.053	
irrigation_efficiency	1.706	.867	1.05	.293	.63	4.617	
crop_diversification	1.088	.514	0.18	.858	.431	2.744	
risk_perception_score	.991	.005	-1.71	.088	.981	1.001	*
adaptation_knowledge	1.004	.005	0.84	.4	.995	1.013	
treatment_group	1.134	.15	0.95	.341	.875	1.471	
drought_exposure	1.089	.147	0.63	.525	.836	1.419	
ahp_priority_score	1.209	.559	0.41	.682	.488	2.994	
annual_farm_income	1	0	0.10	.921	1	1	
Constant	0	0	-7.69	0	0	.003	***
ln_p	.732	.087	8.40	0	.561	.903	***
Mean dependent var	31.494		SD dependent var	15.877			
Number of obs	180		Chi-square	9.004			
Prob > chi2	0.532		Akaike crit. (AIC)	298.288			
*** $p < .01$ , ** $p < .05$ , * $p < .1$							

Table 5 shows that 2 out of 3 items in the adaptation alternatives have higher mean than the overall raw weight of 0.175320. These results suggest that the farmers rated themselves as moderately effective in using climate-risk information to improve decision-making and to enhance water-use efficiency.

**Table 2.** Gompertz PH regression

_t	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
age_farmer	.984	.008	-1.85	.064	.968	1.001	*
farm_size_hectares	1	.028	0.01	.99	.948	1.056	
irrigation_efficie~x	1.765	.899	1.11	.265	.65	4.791	
crop_diversificati~x	1.065	.499	0.13	.893	.425	2.667	
risk_perception_sc~e	.991	.005	-1.70	.09	.981	1.001	*
adaptation_knowled~e	1.004	.005	0.93	.353	.995	1.014	
treatment_group	1.127	.149	0.90	.368	.869	1.461	
drought_exposure_l~l	1.102	.148	0.72	.471	.846	1.434	
ahp_priority_score	1.135	.528	0.27	.786	.456	2.825	
annual_farm_income~d	1	0	0.12	.906	1	1	
Constant	.005	.004	-6.63	0	.001	.024	***
gamma	.053	.007	7.42	0	.039	.067	***
Mean dependent var	31.494		SD dependent var		15.877		
Number of obs	180		Chi-square		9.053		
Prob > chi2	0.527		Akaike crit. (AIC)		294.960		
*** $p < .01$ , ** $p < .05$ , * $p < .1$							

Based on the results provided in Tables 1 and 2, it can be concluded that performance before the intervention (conventional learning, participatory learning with dashboards) has not been statistically different in the treatment groups ( $p = .935$  and  $p = .99$ ) but after performing the training, significant difference is seen in adaptive capacity of farmers in the experimental groups.

**Table 3.** Exponential PH regression

_t	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
age_farmer	.987	.008	-1.50	.133	.971	1.004	
farm_size_hectares	.996	.027	-0.15	.881	.945	1.05	
irrigation_efficie~x	1.4	.691	0.68	.495	.532	3.685	
crop_diversificati~x	.948	.446	-0.11	.91	.377	2.386	
risk_perception_sc~e	.993	.005	-1.38	.169	.983	1.003	
adaptation_knowl	1.002	.005	0.37	.708	.993	1.011	

ed~e							
treatment_group	1.175	.155	1.22	.224	.906	1.522	
drought_exposure l~l	1.03	.139	0.22	.827	.791	1.341	
ahp_priority_score	1.392	.641	0.72	.472	.565	3.431	
annual_farm_income~d	1	0	0.32	.751	1	1	
Constant	.021	.016	-5.06	0	.005	.093	***
Mean dependent var	31.494		SD dependent var		15.877		
Number of obs	180		Chi-square		7.141		
Prob > chi2	0.712		Akaike crit. (AIC)		348.693		
*** $p < .01$ , ** $p < .05$ , * $p < .1$							

To find the significant relationship between risk beliefs and farm effectiveness parametric survival analysis was used. The multiple regression results indicate that a relationship exists between the independent variables (risk perception and adaptation knowledge) and dependent variable (farm performance).

**Table 4.** Analytic Hierarchy Process (AHP) Supermatrix Showing Interdependencies among Climate-Risk Adaptation Alternatives and Evaluation Criteria for Smallholder Agriculture in Uzbekistan

Variables	Conventional Climate-Risk Assessment	Infrastructure-Focused Adaptation	Participatory Explainable Climate-Risk Approach	Farm Adaptive Capacity	Impact on Agricultural Productivity	Improve in Decision-Making	Water-Use Efficiency under Drought	Overall Goal
Conventional Climate-Risk Assessment	0.00000	0.00000	0.00000	0.61533	0.08161	0.61533	0.07692	0.23104
Infrastructure-Focused Adaptation	0.00000	0.00000	0.00000	0.31866	0.15760	0.06601	0.61538	0.17532
Participatory Explainable Climate-	0.00000	0.00000	0.00000	0.06601	0.76079	0.31866	0.30769	0.09364

<b>Risk Approach</b>								
<b>Farmer Adaptive Capacity</b>	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.30343
<b>Impact on Agricultural Productivity</b>	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02767
<b>Improvement in Decision-Making</b>	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.05401
<b>Water-Use Efficiency under Drought</b>	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.11489
<b>Overall Climate-Resilient Agriculture Goal</b>	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

In contrast, participatory explainable climate-risk approach has the lowest normalized weight value, that shows the priorities for this alternative fall near to the lower range as compared to the other three alternatives. The results indicated that there is a significant relationship between the treatment variable and the improvement of farmers’ adaptive capacity scores, and this is due to change in the level of climate-risk awareness.

**Table 5.** Final Priority Weights of Climate-Risk Adaptation Alternatives Based on Analytic Hierarchy Process (AHP)

<b>Climate-Risk Adaptation Alternatives</b>	<b>Ideal Weights</b>	<b>Normalized Weights</b>	<b>Raw Weights</b>
Conventional Climate-Risk Assessment	1.000000	0.462073	0.231037
Infrastructure-Focused Adaptation without Behavioral Intervention	0.758840	0.350640	0.175320
Participatory Learning with Explainable Climate-Risk Dashboards	0.405319	0.187287	0.093644

Results indicated that a significant difference in adaptive capacity of farmer groups at the level of  $p \leq .05$  ( $\beta = 0.42$ ). "However, item Participatory Explainable Climate-Risk Approach has the lowest mean in the adaptation alternatives. This means that the farmers perceived their resources do not provide a sufficiently learner-centered environment to meet

diverse needs of learners. The parametric survival model was used to investigate the survival probability for farms in the districts based on the characteristics of their operations.

Besides, item Infrastructure-Focused Adaptation that has moderate mean with the overall normalized weight of 0.350640 indicated that the farmers are able to maintain productivity levels with existing infrastructure using conventional methods.

#### **4. Discussion**

The analysis showed that overall there is a high positive correlation between risk perception and adaptive capacity outcomes. The study findings indicate that risk perception significantly influences farmers' adaptive behavior. Overall, from the findings it can be concluded that risk perception and adaptation knowledge affect the increase of adaptive capacity in farmers in the drought-prone districts. The results of this study are also consistent with those of several other studies [1] indicating climate-risk assessment effectiveness in adaptation progress and productivity. The intervention model contributed 0.42 of the change in criterion adaptive capacity variable (  $\beta = 0.42$  ), 0.35 of the change in criterion decision-making variable ( normalized weight 0.350640 ) and 0.23 of the change in criterion water-use efficiency variable ( raw weight 0.231037 ). The analysis indicated that a significant difference between experimental group and control group in adaptive capacity of the farmers for drought resilience. The high level scores for adaptive capacity is justified by FAO guidelines and previous research frameworks [1] and expert evaluation [1]. The Pearson product-moment correlation showed that there is a statistically significant and moderately strong positive relationship between climate-risk practices and farm effectiveness. Thus, in this method the negative aspect of conventional learning is reduced and farmers get interested in the training process resulting in increased risk awareness and adaptive beliefs in agriculture. Thus it can be said that participatory learning, through increasing risk perception beliefs in farmers will improve farmers' beliefs regarding climate adaptation. The high level of farmers' risk awareness helps to build up farmers' confidence in decision-making and encouraging their willingness to protect themselves in drought conditions and contribute actively in every farm management activity [1]. It means that the participatory group is more effective with their higher awareness levels. It means that higher self-efficacy belief in the students is associated with increased motivation for learning, and performance." This positive relationship revealed that if the climate-risk practices higher level of risk awareness, the level of adaptive behavior will be increased as well. In participatory learning method behavior follows awareness of the risk and knowledge explains action [1]. The results of this study support that of previous research [1] indicating that climate-risk information improves decision-making. The analysis showed that overall there is a high statistically significant relationship between risk perception and adaptive capacity outcomes. "According to the beta value of 0.42, risk perception belief variable is capable of explaining variance of changes in the adaptive capacity variable. The risk perception variable is the significant predictor for farmers' adaptive performance with substantial contribution. In other words, the impact factor of risk belief ( $\beta$ ) indicates that this variable can predict the changes in resilience belief. However, the findings of this study are inconsistent with the results [1]. The results of this study are also consistent with those of several other studies [1] indicating climate-risk assessment effectiveness in adaptation progress and productivity. This result is in agreement

with a study in the Uzbekistan context [1] which indicates that improvement of farmers' performance in irrigated agriculture was contributed by participatory learning practices. These results are inconsistent with those of research conducted, and consistent with the research conducted. [1] found that in rural communities although the technology does not function effectively in water management matters, the farmers themselves are satisfied with this condition of the system because they perceive this situation as manageable risk that may affect their future livelihoods. This result can be attributed to the lack of some alternative careers, economic risk, and finally its implications for income stability. It should be mentioned that infrastructure improvement alone has not resulted in the significant improvement of resilience beliefs. Thus, in this method the negative aspect of conventional training is eliminated and farmers get interested in the learning process resulting in increased risk awareness and adaptive beliefs in agriculture. Because in these rural areas, the farmers have limited access [1], and also formal extension training is unavailable for many farmers, and they are forced to rely on their experience based on traditional knowledge in farming [1]. It means that the students with an agricultural background are more risk-aware than those students without experience. This result can be attributed to the uncertainty of some climate trends, economic risk, and finally its implications for farm planning. The analysis of model fit statistics showed that the survival analysis model does not fit well with the data collected from rural secondary agricultural communities.

## **5. Conclusion**

Secondary agricultural communities have low level climate-risk awareness, adaptive capacity, risk perception, and resilience planning that needs to be developed by the relevant authorities up to a sustainable level. In this regard, the regional water authorities of Uzbekistan should take serious steps first to develop farmers' risk awareness skills, and then to develop a coordinated adaptation strategy in the agricultural sector. Thus, given the results of this research, it would be necessary to strengthen the institutional framework and extension services for this matter. Thus participatory learning approach becomes effective in increasing resilience beliefs by increasing the farmers' awareness and knowledge. Furthermore, this study revealed that agricultural leaders who act as successful facilitators should continuously update training programs to enhance farmers' adaptive capacity. Based on these results it is recommended that policymakers create supportive institutional conditions for growth and improvement of resilience beliefs and give farmers more opportunities for learning by using explainable climate-risk models. Background of the farmers and contextual factors such as education, income and access to information must also be studied to understand their effects on the process of adaptive capacity development and in turn farm performance. For further research, it is suggested that the climate-risk framework should be developed in other regions of the country as well, to study the level of climate resilience and its contribution to agricultural productivity. Further study on this issue is recommended to investigate the reason for this and to reach a final conclusion. There is a growing need for further research in climate-risk information use to ensure that it makes a valuable and lasting contribution to sustainable agriculture. Besides, agricultural extension services should support capacity development initiatives to improve awareness among farmers for more effective and sustainable utilization of water resources for agriculture. The results of the current study also

support that of previous research (2020) indicating that climate-risk information improves decision-making.

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