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Impact Of Climate Change on Crop Yields in Uzbekistan's Agricultural Zones

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Abstract

Rising as a critical threat to global sustainability, food security, and climate change, Uzbekistan has an increased focus on areas sensitive to heat and water. The landlocked Central Asian country is facing myriads of rising temperatures, declining precipitation, and increased frequency of extreme weather events, all of which significantly impact agricultural productivity. This research aims to analyze the impact of climate variability on the crop yields in the key agricultural regions of Uzbekistan, which include Fergana Valley,

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Khorezm, Karakalpakstan, and Syr Darya basin. With the help of Geographical Information System (GIS), remote sensing, and machine learning, we investigate spatiotemporal trends of climatic variables such as temperature, precipitation, evapotranspiration, and vegetation indices. This research also incorporates historical yield data of major crops, such as cotton and wheat, to simulate the relationship between environmental stresses and agricultural performance. Our findings indicate, particularly in areas reliant on surface irrigation, the yield losses often associated with climate anomalies highlighting negative yield impacts during drought periods and increased yields during wetter years, also referred to as 'yield hijacking'. The project aims to develop an evidence-based constructive adaptive agriculture policy framework that focuses on climate impact mitigation strategies, climate hazard resilience enhancement, resource optimization, and improved food security in Uzbekistan.

Keywords:

Remote sensing GIS, machine learning, vegetation index, adaptation, evapotranspiration, and domains of artificial intelligence.

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Introduction

Overview of Climate Change in Uzbekistan

Uzbekistan, a Central Asian country, faces severe climate issues that threaten its economy and agriculture. This region is experiencing a temperature rise, as observed in the rest of Central Asia. Their rise is perplexing as it is already over 2 times the global yearly temperature surge (AP News, 2023). Additionally, the region is already prone to extreme weather, changes to precipitation, and other irreversible factors that spike evaporation rates. These changes coupled with Uzbekistan's arid climate will rapidly output what we know as desertification, ecosystem devastation, and depletion of water sources. Other than the climate concerns, a further example would be the drying up Aral Sea. Despite being a formerly large body of water, it has been reduced to a mere remnant because of over-utilization of water for irrigation purposes (Carrington, 2024). The deterioration of the Aral Sea has resulted in uncontrollable emissions of poisonous dust which have impacted public health and the environment. This serves as a reminder of Crimea’s expiring climate concerns that need urgent attention (Mustapha et al., 2017).

Rising temperatures and changing precipitation patterns threaten the vibrancy of Uzbekistan's agriculture sector. The alteration in seasonal precipitation has led to flooding in some years while also creating severe droughts in others, complicating crop planning and water resource management. Furthermore, global warming is causing a decrease in the size and flow of glaciers, which endangers the reliability of traditional irrigation systems that predominantly rely on meltwater from mountain glaciers. These changes create uncertainty in agricultural production trends, especially in key regions such as the Fergana Valley and Khorezm, where agricultural practices have historically relied on stable climate conditions over the continual shift and adaptation of weather patterns.

Importance of Agriculture in Uzbekistan’s Economy

Agriculture is crucial for Uzbekistan's economy, in terms of its contribution to 28% of the GDP and its engagement of approximately 25% of the total workforce. Employment and food security for the rural and semi-urban populations make this sector important. The agricultural sector of Uzbekistan is diverse because of the geographical differences in the country, enabling the growing of cotton, wheat, fruits, and vegetables (Uzakbaeva & Ajiev, 2022). Uzbekistan's agricultural exports have always been dominated by cotton, while wheat is becoming increasingly important for food security. Still, the industrial agribusiness is highly exposed to the climate risks because it relies on irrigation which uses over 90% of the country's water supply. This dependence is particularly acute in the Amu Darya and Syr Darya river basins, making agriculture susceptible to water availability. Climate change already impacts these critical water resources; reduced winter precipitation in the Tien Shan and Pamir mountains results in less river flow and weaker water supply during the growing season in key agricultural areas (Huber et al., 2022).

In addition to the diminished water supply, the increasing rate of destructive floods and heat waves has sharply reduced crop yields, particularly for water-intensive crops like cotton and wheat. One UNEP Study focuses on the problem emphasizing that the worsening climatic conditions are increasing the rate of soil salinization which is already accelerated due to enhanced evaporation and inefficient irrigation in a changing climate (Kulkarni & Jain, 2023). The stressed agricultural productivity poses significant threats to food security, weakens economic resilience, and deepens threats to environmental sustainability. Thus, if Uzbekistan wants to preserve future harvests coupled with steady incomes for rural workers, they have to, with the weather, agricultural practices change (Intergovernmental Panel on Climate Change [IPCC], 2023).

Statement of the Problem and Purpose of the Study

Understanding the impact of climate change on agriculture in regions like Uzbekistan is gradually receiving attention. However, climate change studies conducted in Uzbekistan fails to uncover details concerning individual regions' challenges. Adaptation strategies exist, but they are limited to governmental policy frameworks and are absent regarding instruments useful to the farmer (Aldosari, 2024). Climate change impacts coupled with the prevailing vicious circles of increasing demand and diminishing supplies of groundwater, rapid soil erosion, and climate exacerbated extreme weather conditions, further aggravate the situation (United Nations Environment Programme [UNEP], 2023). The overall combination of these interrelated factors intensifies the struggle to achieve food security and sustain consistent yields of crops. Increased temperatures will likely lead to more frequent droughts in Uzbekistan. Crop yields in the southern regions are expected to drop by 15% due to sustained agricultural droughts if the current trend continues (Spoorthi et al., 2021). However, the latest analysis of the climate in Central Asia indicates the occurrence of agricultural droughts in the southern region more than previously thought. Additionally, efforts to meet these new challenges will make the situation worse for water allocation, which is already managing a tense water management situation (Balavandi, 2017).

His study aims to address this problem by utilizing cutting-edge geospatial technology, such as GIS, remote sensing, and machine learning, to analyze Uzbekistan's climate variability and crop productivity relationship. Analyzing yield data in the context of the temperature, precipitation, and evapotranspiration will enhance the understanding of the climate change impact on crop yields in various agricultural zones (Neethu & Ramyaprabha, 2025). In addition to contributing to the scholarship on the climate-crop interaction relationships, this study seeks to provide applied recommendations for developing adaptive plans to ensure evidence-based climate change mitigation sustains Uzbekistan's agricultural output.

Key Contribution

- Designed a thorough framework showing agricultural direct, indirect, and socioeconomic effects of climate change.
- Using large-scale regional survey data, investigated how socio-demographic elements affect farmers' adoption of climate-smart irrigation technologies (CSIT).

- Quantified yield and income differences between CSIT adopters and non-adopters show clear advantages of adoption under climate stress.
- Identified regional obstacles to adopting CSIT and mapped vulnerable areas using GIS analysis to facilitate focused adaptation measures.

The following segments offer a comprehensive evaluation of the impact of climate change on agriculture in Uzbekistan. The first part sets the context, describes the issues, and highlights the importance of developing climate-smart agriculture within the ever-increasing temperature fluctuations. Section 2 examines earlier studies pertinent to Central Asia on regional case studies, adaptive agricultural technologies, and effects of climate change. Section 3 covers the analytical framework, data sources, and tools, including GIS and remote sensing used to evaluate regional vulnerability and technology adoption. Section 4 offers empirical results on climate trends, socioeconomic factors of CSIT adoption, and comparative study of yield and income outcomes between adopters and non-adopters including regional variations. Emphasizing the need of focused interventions, Section 5 compiles the main results and supports laws to improve sustainable farming methods and climate resilience in Uzbekistan.

Literature Survey

New research underscores the rapidly changing state of agriculture in Uzbekistan. To highlight the impact of climate change on agricultural practices, Rakhmatova et al. (2024) forecast significant temperature alterations as well an exacerbated drought situation for most of the country's regions under various climate scenarios (Juraev & Kim, 2024). In addition, the World Bank (2023) states that economic impacts of climate change in Uzbekistan would be devastating in the absence of climate adaption measures, estimating a contraction of 10% by 2025, with agriculture being the foremost casualty (Ibrahim et al., 2024; Liutin & Dower, 2023; Nakamura & Lindholm, 2025). Social and environmental consequences of the Aral Sea region degradation are dire and catastrophic. A rapid assessment by UNDP (2023) indicates the region's public health crisis and the declining agricultural productivity due to reduced soil fertility and deteriorating water quality (Pathak et al., 2023). Moreover, a report from the International Union for Conservation of Nature (IUCN, 2025) indicates that although there has been increased wheat production, it has resulted from unregulated practices that erode land and agricultural resilience, highlighting the need for sustainable land management policies (Krishnaraj et al., 2020; Assegid & Ketema, 2023; Rakhmatova et al., 2024).

To resolve its water scarcity issues, Uzbekistan is investigating innovative irrigation methods. In discussing the challenges and potential of employing water-saving methods such as drip irrigation, Liutin and Dower (2023) highlight the importance of collaboration among all stakeholders to improve water efficiency (State Statistics Committee of Uzbekistan, 2024). The United Nations Environment Program (UNEP, 2024) also stresses the need to replace outdated irrigation methods as they exacerbate water scarcity and promote sustainable water management practices in agriculture (United Nations Development Programme [UNDP], 2023).

Advancements in machine learning show promise for crop yield prediction. With time-series data, Yan et al., (2025) show that hybrid models including Random Forest and Bagging Regressor can reasonably forecast crop yields, so supporting agricultural planning (Karimov & Bobur, 2024; International Union for Conservation of Nature [IUCN], 2025). Pathak et al., (2023) similarly underline the effectiveness of combining several data modalities, including satellite imagery and weather data, to improve the accuracy of yield predictions at sub-field levels (Menon & Deshpande, 2023; United Nations Environment Programme [UNEP], 2024).

Soil salinity thus seriously threatens agricultural output. Excessive soil salinity could lower crop yields by up to 70%, according to a UN FAO report (2024), thus encouraging the acceptance of salt-resistant crops and regenerative farming methods (World Bank, 2023; International Union for Conservation of Nature [IUCN], 2025). In line with this, by processing remote sensing data into feature-based representations, a 2022 Huber et al. study indicates that Extreme Gradient Boosting (XGBoost) models can efficiently forecast crop yields, even in demanding conditions (Kulkarni & Jain, 2023).

Proposal Method

Climate change is having a progressive impact on Uzbekistan. The country is experiencing more obvious changes in temperature, declining annual rainfall, increased frequency of extreme events such as torrential rains and heat waves. These climate-related changes have profound social and economic impacts in a country where agriculture is the cornerstone of the economy and sustains a large part of the population. This research analyzes the changes in temperature of Uzbekistan over the last few decades with focus on areas where agriculture is of particular significance. The research aims to find the areas most at risk by analyzing the position and time of these climate changes. Gaining the understanding needed to address issues like decreasing agricultural productivity, including declining crop yields nationwide, intellectual precedes understanding the problem which is the focus of this study.

This research will utilize modern technology and data analysis tools to evaluate the impact of climate change on agriculture in Uzbekistan. It will compile weather records, scrutinize satellite images alongside other global databases, and satellite databases documenting the history of the region's climate and agricultural practices to monitor concerns regarding temperature, rainfall, and drought for longer periods. GIS will aid in mapping agricultural zones and analyzing pertinent factors such as land utilization, crop types, and water resources to evaluate the impact of these changes on many regions in the country. Remote sensing will facilitate monitoring vegetation, soil moisture levels, and water scarcity indicators in vast farmland areas. WUSe, a program designed to simulate the flow of irrigation water, project future requirements for water given changing climatic factors, will aid in climate condition forecasts. Trends between climate factors and crop yield will be detected using Random Forest and XGBoost which deepens the analysis and provides more precise impact forecasts on various regions.

The investigation will probe closely how Uzbekistan's agricultural output is both directly and indirectly impacted by climate change. It will look at how increasing temperatures affect important phases of crop development including germination, flowering, and maturation and how changes in rainfall pattern and water availability affect irrigation practices and harvest results. The study will also examine how climate change is aggravating biotic pressures, such as the spread of pests, invasive species, and plant diseases, all of which help explain declining yields. Data from drones, satellite images, and IoT-based field sensors will be used to monitor crop health and identify early indicators of stress brought on by shifting climate conditions, so tracking these changes on the ground. The study will replicate possible yield losses using future climate projections, so generating risk maps highlighting the crops and areas most at risk important insights that can help more focused adaptation strategies and better regional planning.

This paper will investigate several approaches meant to make Uzbekistan's agriculture more resilient to help address the increasing difficulties presented by climate change. Among these are urging the acceptance of drought- and salt-tolerant crop varieties, modern irrigation techniques like drip and sprinkler systems to use water more efficiently, and crop diversification to lessen reliance on single-crop farming. The study will also examine the possibilities of digital tools such as farming advice and local weather updates offered by mobile apps to assist in improved farmer decisions. The study will also evaluate national agricultural policies and institutional support structures, pointing up areas where policy changes might enhance efforts at climate adaptation. The results will result in a set of pragmatics, forward-looking suggestions meant to direct future investments, policy changes, and cooperative research to preserve Uzbekistan's agricultural sector in face of a changing climate.

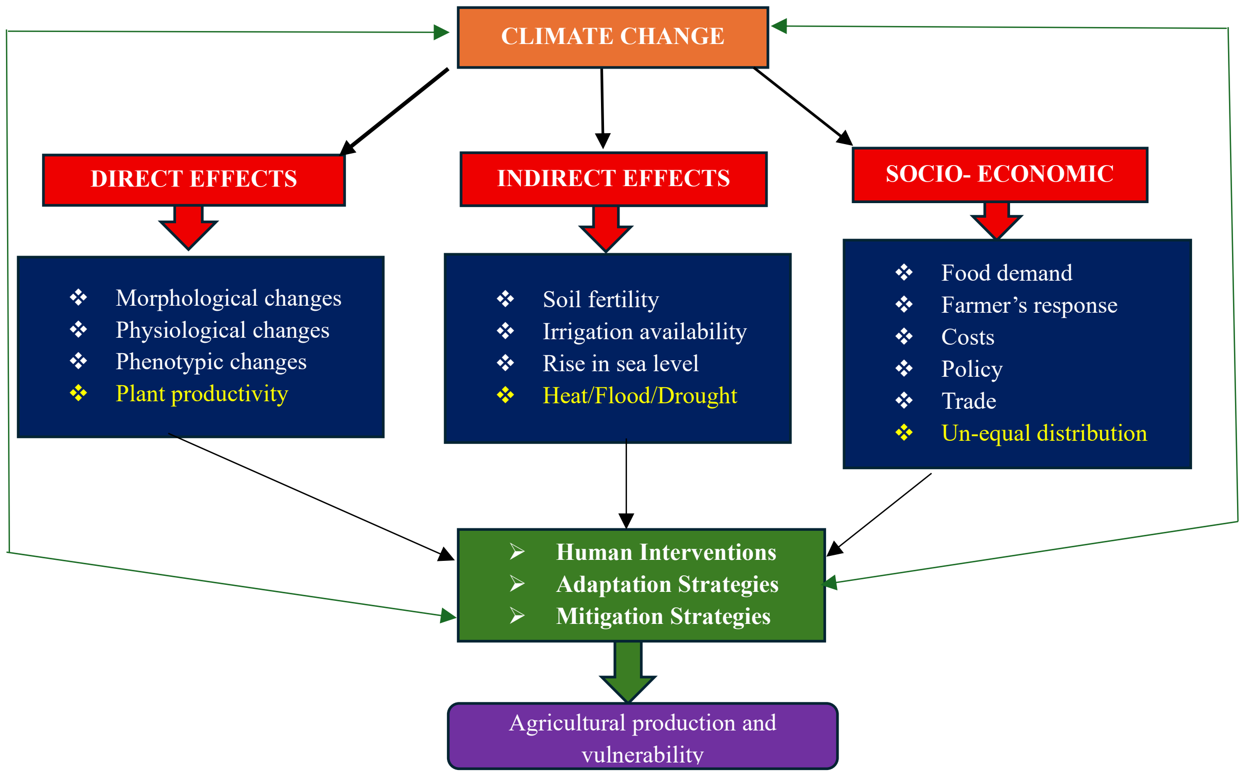

Figure 1: Climate change impacts on agriculture

Figure 1 offers a framework showing three main dimensions of how climate change affects agriculture: direct effects, indirect effects, and socioeconomic consequences. The direct effects are those of which changing climate conditions affect the physical development and growth of crops that is, through changes in growth patterns or lower production. More often occurring extreme weather events, declining water resources, and soil degradation all which strain farming systems directly from more general environmental changes. Socially, climate change influences market dynamics, food production costs, and demand all of which have an impact on smallholder farmers most especially. Especially in climate-sensitive areas like Uzbekistan, the framework stresses the critical need of both adaptation strategies like drought-resistant crops and mitigating techniques low-emission farming to build resilience and lower vulnerability.

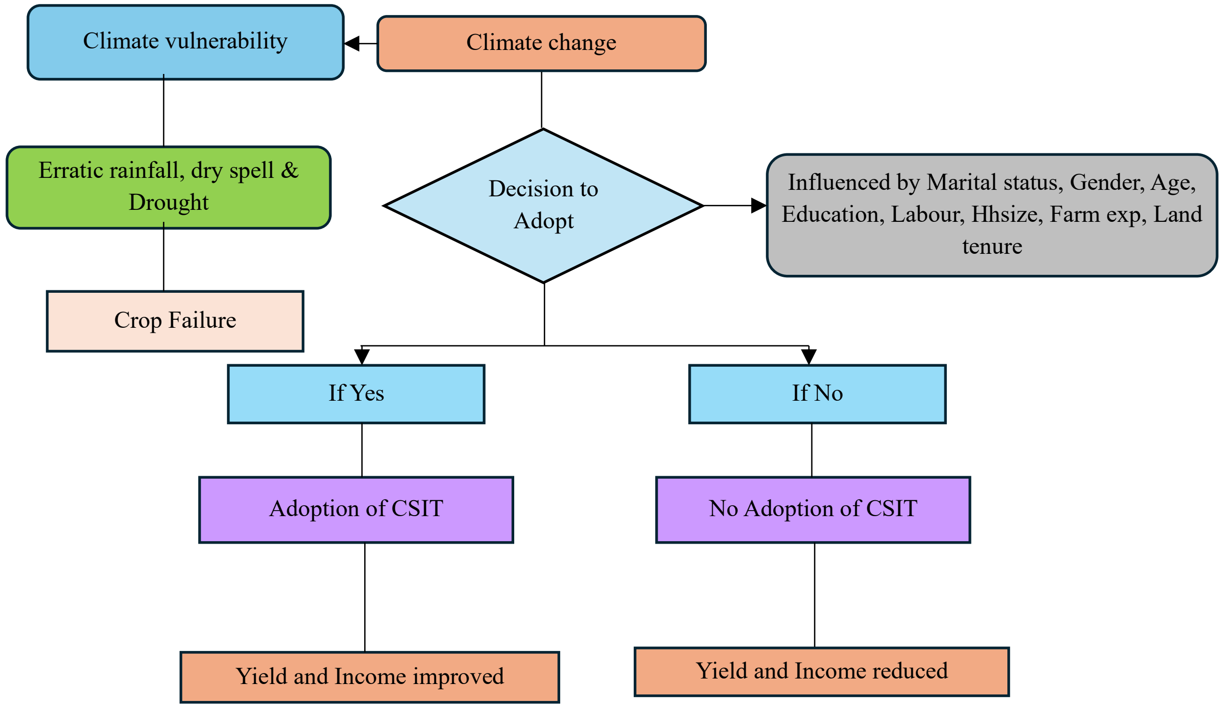

Figure 2. Climate change, CSIT adoption, and farm outcomes

Figure 2 illustrates the impact of agricultural decisions on climate change. Increased climate vulnerability depicted in the trends like erratic rainfall, prolonged periods of drought, and dry spells can lead to severe crop losses and compel farmers to alter their operational methods. One crucial decision they now have to make is whether or not to adopt climate-smart agricultural technologies (CSIT). A myriad of personal and socio-economic factors impacts this decision including, but not limited to, marital status, gender, age, education level, labour availability, household size, farming experience, and land ownership. Adopting CSIT strengthens resilience because farmers tend to experience greater yields alongside improved income. On the other hand, failing to adopt these technologies exposes farmers to chronic losses in agricultural yields and income, thereby deepening their vulnerability. This number underlines the need for well-informed, inclusive policies aimed at aiding CSIT acceptance as a primary step in fortifying agriculture against climate change impacts.

Results and Discussion

As indicated in the study of "Long-Term Climate Trends in Uzbekistan," average temperatures have increased alongside a decrease in rainfall across numerous regions in the country. These changes are especially acute in important agricultural regions such as Fergana Valley, Samarkand, and Khorezm. Soil moisture deficits as a result of prolonged dry periods coupled with more frequent extreme weather directly inhibit the germination and growth of major crops. According to the survey of over 600 farmers, these climate changes are the primary reason for the adoption of new technologies and shifts in irrigation practices. According to the results of the study, socioeconomic variables, such as education, age, occupation, household size, and access to information, have a better effect on climate-resilient irrigation practices and adoption of drip and sprinkler systems than farmers' adaptive capacity.

Table 1. Regional impact of CSIT adoption on yield and income

Region	Adoption Rate (%)	Avg. Yield (tons/ha)	Yield Change (%)	Avg. Income ($/year)	Income Change (%)	Main Barrier
Fergana	70	4.8	+32	3,200	+28	High initial investment
Samarkand	60	4.5	+25	2,900	+22	Technical knowledge gap
Bukhara	56	4.3	+24	2,700	+18	Infrastructure limitations
Surkhandarya	42	3.9	+15	2,400	+12	Lack of extension support
Khorezm	50	4.1	+20	2,600	+16	Limited access to finance

Table 1 shows the difference in the use of climate-smart irrigation technologies between the major farming regions of Uzbekistan and their effect on income and yield. The Fergana region yields the highest income and yield gains of 28% and 32% respectively with a 70% adoption rate. Moderate adoption also yields significant improvements in Samarkand and Bukhara. Khorezm and Surkhandarya, with lower adoption rates, show smaller improvements. From the table, the need for tailored region-specific support to improve adoption and resilience is evident; however, in Fergana, the region-specific barrier includes high investment costs, technical knowledge gaps in Samarkand, infrastructural constraints in Bukhara, lack of extension support in Surkhandarya, and in Khorezm, limited financing all contribute to a low adoptions and widening gaps.

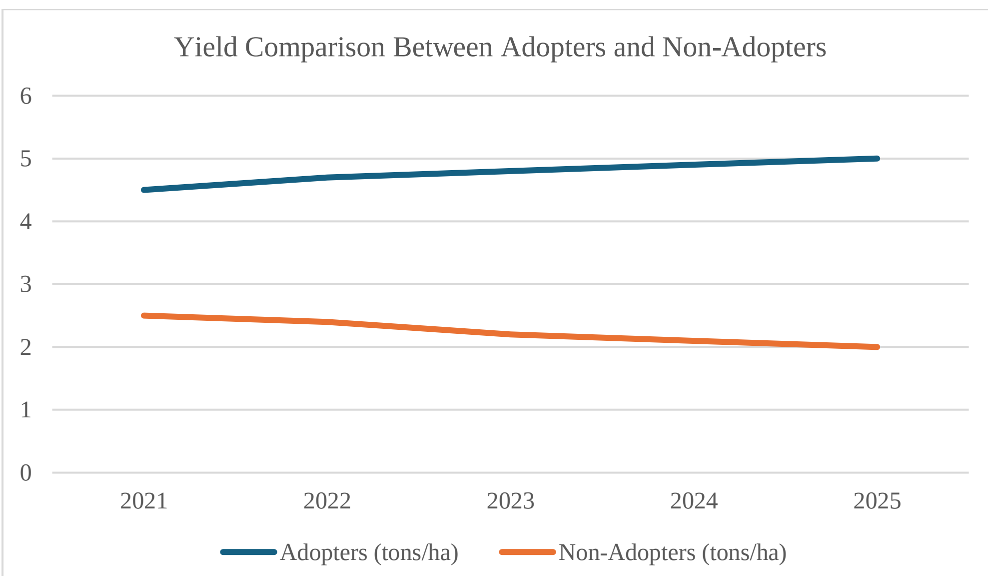

Figure 3. Yield comparison between adopters and non-adopters (2021-2025)

This Figure 3 represents the yield (tons/ha) of adopters and non-adopters from 2021 to 2025. In contrast the yield for non-adopters declines from 2.5 tons/ha in 2021 to 2.0 tons/ha in 2025, the yield for adopters rises steadily and by 2025 it reaches 5.0 tons/ha. The annual widening difference in yields between adopters and non-adopters highlights the increasing advantages of implementing the practice.

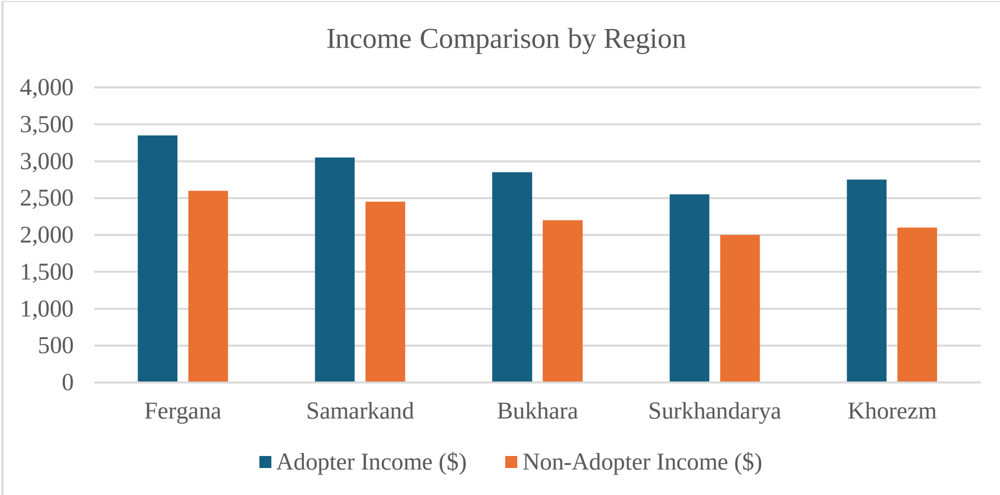

Figure 4. Income comparison between adopters and non-adopters by region (2025)

The Figure 4 shows, for five areas—Fergana, Samarkand, Bukhara, Surkhandarya, and Khorezm the income levels of adopters and non-adopters. Adopters regularly make more than non-adopters in every area, so stressing the financial advantages of implementing better technologies or practices. For Fergana, for example, adopters made $3,350 while non-adopters made $2,600; similar income differences were clear in the other areas. This chart makes it abundantly evident how favourably adoption is for the economy and facilitates simple comparison of regional income disparities.

Farmers who adopted climate-smart irrigation technologies reported an average yield increase of 25–32%, whereas non-adopters faced yield declines of up to 15%. Income also showed a similar trend; adopters saw a 20–28% increase in farm income, especially in years with inconsistent rainfall. These results show how well contemporary irrigation helps to stabilize output under environmental pressure. Furthermore, GIS studies and remote sensing enabled the identification of sensitive areas most at risk resulting from inadequate infrastructure and water supply. These areas revealed more sensitivity to yield shocks brought on by climate change. The outcomes underscore the importance of targeted climate adaptation interventions, such as improved infrastructure, enhanced educational outreach for farmers, and policy intervention, to mitigate the impacts of climate change on the agricultural economy of Uzbekistan.

Conclusion

The effects of climate change on Uzbekistan's agriculture, including the physiological disruption of crops as well as the growing economic hardship for farming communities, have been deeply and multi-dimensionally studied. Although the adoption of climate-smart irrigation technologies (CSIT) has the potential to significantly increase yields and incomes, the adoption rate of this technology has not been homogeneous due to region-specific knowledge, financing, and infrastructure barriers. The striking difference in results between adopters and non-adopters accentuates the role of informed technology adoption in enhancing resilience. Integrated policy frameworks combined with targeted financial and technical assistance in capacity-building activities that prioritize vulnerable regions and smallholder farmers urgently aim to defend agricultural sustainability amidst escalating climate variability.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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