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To cite this article: Ahmad Hamidov, Akmal Akramkhanov, Mukhamadkhan Khamidov, Umid Juraev, Shakhnoza Abulkosimova & Katharina Helming (05 Feb 2026): Technological and policy challenges in implementing water-saving irrigation technologies: a case study from Uzbekistan, International Journal of Water Resources Development, DOI: [10.1080/07900627.2025.2612485](https://doi.org/10.1080/07900627.2025.2612485)

To link to this article: <https://doi.org/10.1080/07900627.2025.2612485>



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Published online: 05 Feb 2026.



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Technological and policy challenges in implementing water-saving irrigation technologies: a case study from Uzbekistan

Ahmad Hamidov ^{a,b}, Akmal Akramkhanov ^c, Mukhamadkhan Khamidov ^b,
Umud Juraev ^{d*}, Shakhnoza Abulkosimova^{a**,e} and Katharina Helming ^{a,e}

^aLeibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany; ^bDepartment of Irrigation and Melioration, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, National Research University ("TIAME" NRU), Tashkent, Uzbekistan; ^cInternational Center for Agricultural Research in the Dry Areas (ICARDA), Tashkent, Uzbekistan; ^dDepartment of Irrigation and Melioration, Bukhara State Technical University, Bukhara, Uzbekistan; ^eFaculty of Landscape Management and Nature Conservation, University for Sustainable Development (HNEE), Eberswalde, Germany

ABSTRACT

Water-saving irrigation technologies (WSITs) are meant to improve water use efficiency. Yet, while these technologies are available, their implementation depends on various factors, including the risk perception of farmers and the existence of social learning. This paper aims to study Uzbek farmers' perceptions of adopting WSITs, focusing on their perceived benefits and challenges. The findings reveal that, while participants are aware of WSITs' benefits (indicating the existence of social learning), such as increased yields, they also recognize significant challenges and risks, including high maintenance costs and limited suitability for local environmental and climatic conditions. Finally, intensive adoption may have potential unintended consequences (e.g. rebound effects).

ARTICLE HISTORY

Received 13 June 2025
Accepted 31 December 2025

KEYWORDS

Irrigation efficiency; sustainability; risk aversion; social learning; rebound effects; Central Asia

Introduction

Policymakers, experts and academic scholars agree that the implementation of modern water-saving irrigation technologies (WSITs), such as drip irrigation and sprinkler irrigation, may support economic growth in agriculture and energy sectors as well as lead to resource use efficiency (Lakhiar et al., 2024). Efficiency improvements are frequently linked with a key technological solution to meet increasing demands for water due to the population growth and climate change (Guppy & Anderson, 2017).

To date, there are two widely used water-efficient irrigation methods: drip and sprinkler. Drip irrigation is considered to be the most efficient form of water saving system at 95% (i.e. of the 100% of irrigation water applied, about 95% is effectively used by the crop), whereas sprinkler irrigation systems at 80%. Traditional furrow irrigation is 60% efficient (Hamidov et al., 2022). Drip irrigation provides water directly

CONTACT Shakhnoza Abulkosimova  shakhnoza.abulkosimova@gmail.com

*Currently at Department of Agronomy and Soil Science, Bukhara State University (BSU), Bukhara, Uzbekistan

**Currently at Faculty of Spatial and Environmental Sciences, Trier University, Trier, Germany

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to the root zone through a network of tubes, emitters and valves. It slowly drips water into the soil to meet the crop growth requirements while minimizing water waste in the field (Guo & Li, 2024). Sprinkler irrigation, which has been in use at farm level since the late 1970s, is another type of high efficiency water-saving irrigation system (Chauhdary et al., 2023). It irrigates crops by simulating natural rainfall and uses a system of pumps, pipes and sprinklers to distribute water over a large area in a controlled manner.

While many studies show the benefits of implementing WSIT, their adoption is often hindered by technical, socio-economic, environmental and institutional barriers. For instance, there is insufficient research on why some farmers resist adopting innovative technologies despite clear benefits, especially in post-socialist contexts (Chatalova et al., 2017; Hamidov et al., 2020). Furthermore, there is also a lack of research on how subsidies and market-based approaches affect adoption (Hong et al., 2024). Finally, limited research exists on how advanced irrigation technologies perform under climate change conditions and address soil health issues (such as soil salinization).

Much of the literature on farmers' adoption of decision-making primarily focuses on farm characteristics as well as financial and institutional factors (e.g., access to credit, tenure security), often overlooking psychological factors like risk attitude (Foguesatto et al., 2020; Liu et al., 2018). Farmers already operate in uncertain environments due to market failures, weather fluctuations, diseases and pests (Perret & Stevens, 2006). In addition to these uncertainties, adopting new technologies introduces even greater uncertainties and risks, primarily due to limited knowledge about their long-term impacts, benefits and returns under real-world climatic and economic conditions. This uncertainty makes investment in new technologies particularly risky (BenYishay & Mobarak, 2019). As a result, farmers' adoption decisions are significantly influenced by their risk perception and risk cognition. Risk cognition refers to farmers' subjective understanding and continuous evaluation of potential risks associated with their decisions, for example, the risks involved in adopting new technologies (Ren et al., 2023). It is particularly linked to how farmers assess the economic, ecological and social benefits of new practices and technologies. Despite these challenges, risk aversion towards new practices and technologies can be mitigated through social learning about their long-term benefits, impacts, risks and challenges (Pronti et al., 2024; Ren et al., 2023). Social learning, which involves acquiring reliable information and knowledge through various networks, can help improve farmers' understanding of these benefits. Therefore, prospect theory dealing with risk aversion and social learning theories could provide essential insights into farmers' risk perception and learning processes. Importantly, most of the research on social learning, and in particular on risk perception, has been conducted in different parts of the world, but not yet in Central Asia.

Adoption of WSITs is particularly critical in regions with an arid climate, such as Uzbekistan, where agriculture is almost entirely dependent on irrigation. The agricultural sector is the primary source of employment in rural areas (Egamberdieva et al., 2025). Around 52% of the rural population in Uzbekistan lives under severe water scarcity, with annual per capita freshwater resources at 531 m³ (World Bank, 2014), well below the United Nations threshold of 1000 m³ per capita for chronic shortage (Varis, 2014). Excessive water loss due to poor irrigation infrastructure, improper functioning of drainage systems, waterlogging and soil salinization – affecting 50%

of the Uzbekistan's irrigated land – are contributing to declining crop yields, deteriorating environmental services and overall threatening long-term food system sustainability. While the region's rapid demographic growth from 20.6 million in 1991 to 37.6 million in 2025 (Stat.uz, 2025) continues to increase pressure on water consumption, climate change is expected to reduce water availability in the region's two key water sources – Amudarya and Syrdarya rivers – by 15% and 5%, respectively, by 2050 (Murzakulova et al., 2020; World Bank, 2013).

Due to these current and expected challenges with water availability, Uzbekistan's government is encouraging the adoption of WSITs to effectively use available water resources, monitor soil salinization and newly develop and reclaim for use an additional 218,000 ha of irrigated land in 2024 (Presidential Decree No. 153 from 5 April 2024) to increase agricultural production. Incentive programmes, introduced on 15 July 2019 and 23 February 2021 (Decrees No. 587 and No. 95 of Cabinet of Ministers) and on 1 March 2022 (Presidential Decree No. 144), encourage farmers to adopt WSIT. More specifically, the Water Resources Development Strategy 2020–2030 (Presidential Decree No. 6024 from 10 July 2020) aims to equip two million hectares (ha) or 50% of total irrigated land, with WSIT by 2030. The government subsidizes 50% of the installation costs for WSIT (around 800 euro/ha), while local banks cover the remaining 50% through low-interest loans over a 10-year period. Farmers who adopt these technologies are also released from unified land taxes for five years and are allowed to grow secondary crops following the main crops such as cotton and wheat. While the area covered by WSITs was just 28,000 ha in 2017, this figure had substantially increased to 1.9 million ha by the end of 2024 (Gov. uz, 2025).

Most studies on WSITs in Uzbekistan have primarily focused on assessing their efficiency through field-based experimental research (Fazliev et al., 2019; Mirshadiev et al., 2018; Yusupov et al., 2025). These studies consistently report significant water savings (40–50%) compared to traditional furrow irrigation, along with benefits such as improved soil properties, reduced irrigation erosion and fertilizer runoff, and increased crop yields. Additionally, plastic mulching was experimented with as a water-saving technology for the first time in a field experiment in Uzbekistan and was found to be an effective irrigation option, particularly for horticulture in hilly areas of the country where water is scarce (Chathuranika et al., 2022). Despite these promising findings, there is limited research on stakeholders' perception of WSITs and the factors influencing adoption among farmers.

The main objective of this paper is to explore how stakeholders perceive the opportunities and constraints associated with WSIT implementation, and to identify the deeper causes of these challenges and risks. By integrating two complementary theories (prospect theory and social learning theory), our study aims to contribute to the broader discourse on the sustainable adoption of WSITs in semi-arid regions like Uzbekistan. To the best of our knowledge, no prior research has investigated WSIT adoption using this combined theoretical approach, especially in post-socialist context.

Theoretical concepts

In order to study the perception of farmers, we looked at different theoretical concepts, which can help us underline the reasons for adopting or failing to adopt the advanced

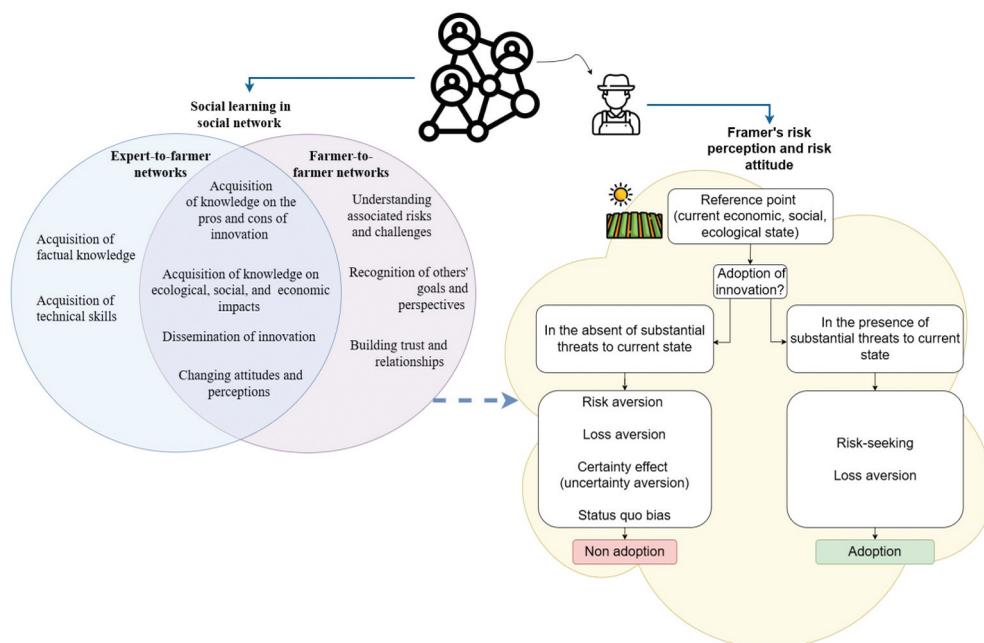


Figure 1. Theoretical integration of prospect theory and social learning in the context of farmers' adoption of agricultural innovations. Left: Social learning about agricultural innovations. A farmer is embedded in a broader social environment – social network – where social learning about innovations occurs. The social network typically distinguishes between expert-to-farmer networks and farmer-to-farmer networks. While these networks facilitate farmers' acquisition of distinct knowledge, the existence of both networks is equally important for the social learning about the innovation. Social learning helps mitigate uncertainties associated with innovations, thereby influencing a farmer's risk perception and risk attitude (the dashed arrow linking to prospect theory). Right: Risk perception and attitude as described by prospect theory. A farmer's risk attitude depends on the domain relative to their reference point. For example, in the absence of substantial threats to the current reference point (i.e., gain domain), a farmer is generally risk-averse towards adopting new innovations, influenced by various cognitive biases. However, in the presence of a substantial threats to the reference point, for example, yield decrease due to severe drought occurrence (i.e., loss domain), a farmer tends to be more risk-seeking due to loss aversion cognitive bias. Source: Authors' visualization.

WSITs. Specifically, prospect theory and social learning theory (mental model) were combined to explain the challenges with WSIT adoption. [Figure 1](#) illustrates the components of prospect theory and social learning in the context of adoption of sustainable agricultural innovations, such as WSITs.

Prospect theory

Prospect theory has been employed to understand the behavioural decisions for choices under conditions of risk and uncertainty. It was promoted by Kahneman and Tversky (1979) as an alternative to the expected utility theory which was a dominated theory in the analysis of decision-making under risk (Levy, 1992). The expected utility theory suggests that individuals make choices between risky or uncertain options by weighing expected utilities (or values) assigned to each outcome of prospects and

selecting the option with the maximum expected utility, assuming that the probabilities associated with each possible outcome are known (Levy, 1992). Prospect theory, on the other hand, suggests that decision-makers assign the value to changes in relation to the reference point (i.e., current state) rather than to final states (Kahneman & Tversky, 1979). Reference point is assumed to be a zero point, where any deviation is perceived as either a gain or a loss. In addition, people tend to place greater value on what they already own (i.e., the endowment effect), and they also tend to place more weight on the potential losses from leaving their current state than the potential gains (i.e., loss aversion), resulting in status quo bias (Kahneman et al., 1991; Lu & Xie, 2014). Loss aversion behaviour also results in risk-averse behaviour in the domain of gains and risk-seeking (or risk-accepting) behaviour in the domain of losses (Kahneman & Tversky, 1979). Moreover, decision-makers tend to favour certain outcomes over uncertain one – the certainty effect – which further reinforces risk aversion. A number of studies have applied prospect theory to study farmers' risk perception and preferences regarding their agricultural decisions. For example, Bocquého et al. (2014) studied French farmers risk preferences in a field-experiment setting and found that farmers exhibit twice the sensitivity to losses than to gains, demonstrating risk-averse behaviour. Prospect theory was also applied to examine the adoption behaviour of farmers such as low carbon agricultural technology (LCAT; Li & Huang, 2023) and adoption of innovation (Höhler et al., 2023). Finally, Li and Huang (2023) assessed the impact of farmers' risk perception and loss aversion on LCAT, where the authors found that farmers with stronger risk perceptions of yield, market and climate risks were more likely to adopt LCAT. As outlined earlier, no studies have been conducted on risk perception in irrigated agriculture in Central Asia.

Social learning theory

Social learning is essential for sustainable development and natural resource management since any intentional change – whether by individuals or groups – is based on learning (Muro & Jeffrey, 2008). Glasser (2007) defined learning as 'the process of acquiring knowledge, skills, norms, values, or understanding through experience, imitation, observation, modeling, practice, or study; by being taught; or as a result of collaboration' (p. 46). Although learning does not always lead to behavioural change – since competing goals, interests and objectives may prevent such change – it remains the primary means through which we form our values, attitudes, concerns and understanding of reality (Glasser, 2007). Reed et al. (2010) define social learning as 'a change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks'. They suggest three main conditions for the occurrence of social learning: (i) a process must demonstrate that a *change in understanding* about the outcomes of specific actions has occurred in the involved individuals; (ii) this must take place *at a wider scale* – 'wider social units or communities of practice'; and (iii) it must occur *through social interactions* between actors within a social network'.

In the context of participatory and collaborative governance in natural resource management, social learning is widely recognized as a key component for building trust, fostering shared understanding, and enabling joint action (Pahl-Wostl et al., 2007).

In the context of the adoption of new agricultural innovations, such as WSITs, the central role of social learning is the dissemination of these innovations through farmers' social networks (Chaudhuri et al., 2021). Farmers social networks involve both offline interactions and online interactions, like mobile phone and radio (Jones-Garcia & Krishna, 2021; Kurbanov et al., 2024).

A number of studies examined the effect of social learning from the interaction among farmers on the adoption of agricultural technologies and their diffusion (BenYishay & Mobarak, 2019; Genius et al., 2014), WSITs (Wang et al., 2020), soil testing and fertilization technology (Wu et al., 2022). Yet there were no studies on social learning in technology adoption in Central Asia. Nakano et al. (2018) found the effectiveness and practical potential of farmer-to-farmer extension programmes for diffusion of new technologies to increase productivity where a small number of key farmers with training disseminated knowledge to non-trained farmers in Tanzania. Similarly, Chaudhuri et al. (2021) studied the role of farmers' social networking and learning for agricultural innovation where the study demonstrated that social learning, dissemination of new knowledge through farmer-to-farmer interaction, is key to adoption of new paradigms, including new technology and cropping methods in India.

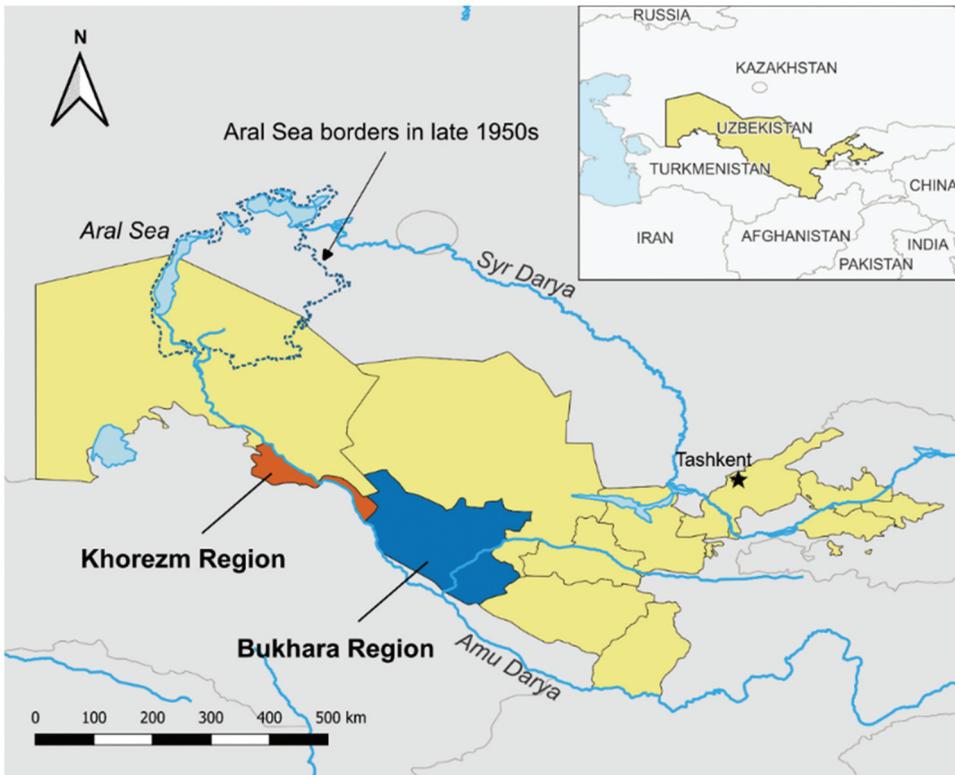


Figure 2. Location of the study regions, Khorezm and Bukhara, within Uzbekistan. Source: Authors' graph.

Materials and methods

Study areas

Within the Amudarya River Basin of Uzbekistan, two study regions – Khorezm and Bukhara – have been selected to understand the perceptions of stakeholders (experts and farmers) with regards to the adoption of WSITs (Figure 2). The regions are populated with diverse ethnic populations such as Uzbeks, Tajiks and Turkmens, and are located in the Central Asian semi desert zone (Khamidov et al., 2020). It has an extremely continental climate with long hot dry summers and cold temperatures during winter. The study areas experience frequent irrigation water shortages and suffer from different levels of soil and groundwater salinity. Additionally, their geographical proximity to the Aral Sea, an ecological catastrophic zone, also makes these regions particularly significant for study. The construction of the Koshtepa irrigation canal by the Taliban government in Afghanistan, which is set to divert up to 30% of the Amudarya's water once completed in 2028, will have an immense impact on local societies in both regions (Abdullaev et al., 2025).

The Khorezm region covers an area of about 6100 km² and is located about 245 km south of what remains of the Aral Sea. The population of Khorezm is around two million people, with 60% of the population residing in rural areas (Xorazmstat, 2022). The rural population is mostly engaged in cotton production, which is the main cultivated crop for that region, followed by winter wheat, rice and various other crops (e.g., vegetables, fruits and forage). The region is located in the lower reaches of the Amudarya River (100 m above sea level), which is the major water source for all water sectors in Khorezm. The river provides irrigation water for 268,000 ha of which more than 11% are severely saline. The region is allocated 15% of Uzbekistan's national river water withdrawals, of which around 94% is estimated to be used for agriculture (Khamidov et al., 2020). However, compared to other regions of Uzbekistan, Khorezm regularly faces water shortages because of intensive upstream utilization.

The Bukhara region covers an area of about 40,200 km² and lies around 400 km south of what remains of the Aral Sea. The region's total irrigated area is 280,000 ha of land, of which close to 142,000 ha (over 50% of the total irrigated area) irrigated with WSITs as of end-2024. The total population is about 2 million, with over 60% of the rural population depending on irrigated agriculture. The annual precipitation in the region ranges from 120–140 mm, with most rainfall occurring outside the growing season, mainly during autumn and winter. Local potential evapotranspiration, estimated at around 2000 mm annually, significantly exceeds precipitation (Khamidov et al., 2023). As a result, large-scale irrigation is necessary for crop cultivation in this region.

Data collection and analysis

The empirical work was based on focus group discussions (FGDs), which is defined as a research technique appropriate for collecting empirical data through group communication on a particular topic (Bitsch, 2004). This technique is not intended to facilitate decision-making or educate people; rather, it is designed to collect data, particularly when the resources for conducting individual interviews are limited. This method does



Figure 3. Focus group discussion in Khorezm region. Source: Authors' photo.



Figure 4. Plenary: Discussion of FGD results in Bukhara region. Source: Authors' photo.

not necessarily require a statistically representative sample of broader population, but rather a purposely selected group of individuals who can work together to jointly construct and analyse a social-ecological system (Nyumba et al., 2018). This approach provides broader insights despite the limited number of participants.

In the frame of this study, four FGDs (two with farmer groups and two with expert groups) were organized in November 2022 in the Khorezm region with three to five participants in each, and one FGD was conducted in August 2023 in the Bukhara region with 10 participants in total (Figures 3 and 4). For the analysis, the Khorezm FGDs were stratified into farmers and experts. Due to limited resources and time constraints, the Bukhara FGD was not stratified and included all stakeholders. As a result, three groups emerged from the analysis: the Khorezm farmer group, the Khorezm expert group and the Bukhara expert-farmer group. The participants were relatively homogenous in terms of age, education, profession and socioeconomic status; a moderator; and an assistant

recorded the discussions and kept notes. Annex 1 provides stakeholder compositions in FGDs in Khorezm and Bukhara regions. The study team contacted local authorities and representatives of farmers' groups to gather stakeholder groups for an FGD. Annex 2 provides an FGD agenda and asked questions.

FGDs were audio-recorded with respondents' consent and subsequently transcribed. These transcripts, together with the notes taken during the FGDs, were analysed using qualitative data analysis software (MAXQDA 2022, VERBI Software). A systematic coding process was applied, involving the development of a coding structure that grouped coding schemes into defined code definitions. This structured set of codes was refined through repeated reviews of the data. Each focus group data was used as a unit of analysis, i.e., group data (not individual data), therefore emergent themes were prescribed to a group as a unit of analysis. The coding scheme categorized responses based on the three questions from the FGDs: (i) specifically perceived advantages of the technologies, (ii) addressing challenges and barriers to adoption and (iii) proposed ways to overcome the identified limitations. Code responses were assigned based on their relevance to these questions, capturing common recurring themes and their frequency (Table 1).

Results: key empirical insights

Perceived advantages of implementing water-saving irrigation technologies

The study findings show that stakeholders generally perceive the adoption of WSITs as advantageous for the environment and their economic status; therefore, they have a positive attitude towards them (Figure 5). The WSITs could address the existing water deficit of the regions and thereby enable sufficient water for crops. For instance, the Khorezm FGD participants quantified the regional deficit as between 30% and 40%, emphasizing that it varies greatly from year to year and noting severe water deficits of more than 50% in 2008 and 2021. Therefore, the adoption of WSIT is perceived by stakeholders as an important step to address water shortages and water-crop demand and eventually increase yields. Specifically, some farmers in Khorezm applied drip irrigation to their cotton fields, increasing yields to 4000 kg/ha (or 60%) compared to previous average yields of 2500 kg/ha.

Furthermore, the adoption of these technologies leads to improved resource use efficiency of agronomic practices. In particular, WSITs require less fertilizer and machinery. They improve fertilizer management, as the amount of fertilizer applied is significantly reduced when it is dissolved in water or liquidized, rather than being spread over the field. Less agricultural machinery intervention, on the other hand, benefits soil health by avoiding soil compaction. Additionally, Khorezm's expert FGD emphasized that the adoption of the WSIT will enable water measuring (also monitoring of the water withdrawal or usage) and facilitate the digitalization of the agricultural sector of the economy.

FGDs revealed established trust among farmers and the ability to communicate about new technologies, resulting from frequent meetings during canal maintenance and water consumers associations' Assembly Meetings. Interestingly, the Bukhara

Table 1. Coding structure for the data analysis.

Coding scheme	Code definition
<i>Advantages of technology adoption</i>	
Saves resources	Time, water (water scarcity), labour
Enables sufficient water for crops	Water-crop demand, water-use efficiency
Saves agro-technological practices	Pesticides, fertilizers, heavy machinery
Enables digitalization	Digitalization
Decreases soil compaction	Soil compaction
Increases economic efficiency	Yields
Enables acquisition of new lands	Irrigation land expansion into desert areas
<i>Barriers and limitations to adoption of the technologies</i>	
Lack of water availability, accessibility and infrastructure	Scarce, shortage, (water) delay, wells, canals, energy (electricity), design of implementation of technologies
Lack of financial resources	Finance, subsidy, loans, interest rate, price of technologies, maintenance cost
Lack of knowledge and extension services	Extension services, farmers' skills, knowledge
Operation and maintenance of technologies	Filters/tubing, clogging, labour-intensive, quality of the technologies
Suitability to the climatic and environmental specificities	Temperature, evaporation, groundwater level, soil texture, soil mechanical properties, salinity, water quality (e.g., muddy)
Negative environmental effects of the technologies	Increased invasive plants/ undesirable vegetation, soil salinity
Institutional factors	Land tenure, insecurity, trust, communication, rules as subsidy (instead loans with low or no rate), few banks, obtaining the loans and subsidy barriers
<i>Proposed ways to overcome barriers and limitations to technology adoption</i>	
Improvement of water accessibility and availability	Well, groundwater, canal management, water storage dams, water transportation
Organization of capacity building activities	Demo sites/ exhibitions, decision-support system, methodological manual, education, skills, knowledge
Provision of extension services	Extension services, experts
Supporting with favourable financial programmes	Subsidies, loans, payment period, water tax exemption, favourable conditions
Improvement of suitability of technologies	Technologies, tubing, localization of technologies, quality of technologies
Stable and adequate electricity supply	Electricity, solar panels
Secure land tenure system	Land tenure

stakeholder groups perceive the WSIT as an opportunity to acquire desert lands for cultivation, i.e., irrigation land expansion into desert areas. Some of the farmers within the Bukhara FGD reiterated that they had already acquired some desert land with the help of the WSITs. This has resulted in potential rebound effects, whereby overall water use efficiency improves, but this leads to an increase in the irrigated area or a

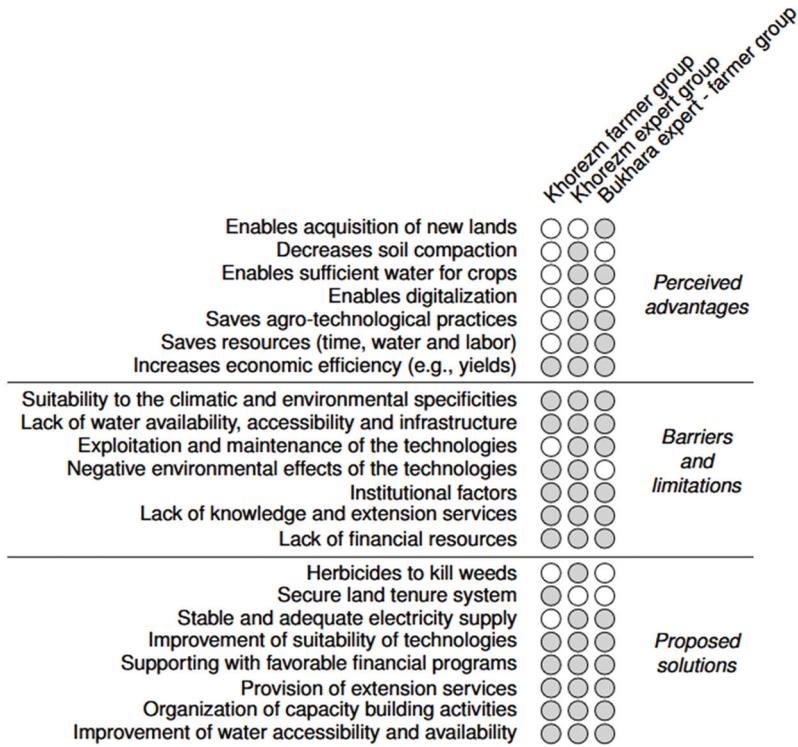


Figure 5. Perceived advantages, limitations and proposed solutions for implementing water-saving irrigation technologies in Uzbekistan. Coloured dots represent agreement among focus group members.



Figure 6. Drip irrigation technology used in the potato field in Uzbekistan. Source: Authors' photo.

switch to more water-intensive crops, as observed by Hamidov et al. (2022) and Nair and Thomas (2023).

Perceived barriers and limitations of implementing water-saving irrigation technologies

Although farmers recognize the advantages of the WSIT adoption, the implementation rate remains low. One of the major challenges with the implementation of technologies raised during the discussion was the *cost of technology*, such as the bank interest rate (i.e., up to 20% per year), technology installation and maintenance cost (Figure 6). Despite the fact that the government is promoting the technology adoption through subsidy programmes, the participants highlighted that the subsidy has not been given in due time because of bureaucratic procedures such as detailed business plans, collateral issues and disruptions with COVID-19 restrictions. Once farmers receive subsidies, they need to implement WSIT in the next five years, otherwise they should return 80% of the subsidy back. Furthermore, the FGD in Bukhara revealed that the loans for the technologies could only be obtained through one dedicated bank – the ‘Agrobank’ – limiting the option of selecting other banks with lower interest rates. Farmers who want to implement the technologies have no choice but to obtain loans from this bank. Only recently, from 2023, the ‘Business Development Bank’ has started providing the loans for farmers to implement the technologies. In addition to the high interest rates, there are barriers to obtaining loans, including the requirement for farmers to have no outstanding loans and a strong loan repayment history (i.e., institutional factors in Figure 5 and Table 1).

I have 100 ha of field. First, I implemented the drip irrigation system on 20–25 hectares. As I was satisfied with the yields, I wanted to instal the technology for the remaining 40 hectares. However, the bank rejected my loan application. The reason was that I first had to pay off the loans for the initial drip irrigation system. (A Bukhara farmer)

Lack of knowledge, skills and adequate extension services in using modern WSIT was identified as another major barrier. For example, farmers often lack knowledge about the appropriate frequency and quantity of water required based on field length or how to properly space furrows in drip irrigation. Additionally, they need guidance on implementing these technologies according to soil characteristics. As WSITs are new and farmers lack the necessary skills, they face difficulties in their use. Access to extension services is often limited, insufficient, too expensive or of poor quality. Installation companies typically install the technology and offer minimal training, demonstrating the technologies only a few times after installation is complete.

The organizations who install the technologies do not teach how to use the technologies. They just come, install and then leave, but farmers then cannot use them as they do not have enough knowledge. (Bukhara FGD)

The service centres just install the technologies and do not provide further services during the maintenance of the technologies. (Khorezm FGD)

Additionally, when the technology malfunctions or is broken, farmers need assistance with repairs, but there is no support provided by the installing companies. The absence of

extension services for maintenance and repair further complicates the adoption and use of these technologies.

Consistent water supply is essential for drip or sprinkler irrigation systems. However, during vegetation periods, water availability is often limited, especially for downstream farmers in the Khorezm region. These farmers reported that water frequently fails to reach their fields on time. For example, some who installed sprinkler irrigation systems could only use them twice during the growing season due to water shortages. In sandy areas of Khorezm, like Khiva, there are multiple zones where water is neither available nor provided in a timely manner.

Water scarcity is not only caused by upstream farmers' overuse but also by poor infrastructure. Much water is lost as it runs through irrigation canals that are not lined with concrete, leading to significant losses before reaching downstream farmers. Additionally, water is typically supplied on a queue basis, but drip and sprinkler systems require regular, consistent water – ideally daily or every other day. In Khorezm, for instance, water is delivered through canals only once a week, while the canals remain closed for the rest of the time. This causes crops to wilt between watering cycles. In one instance, drip irrigation was installed, but a 20-day delay in water supply almost caused cotton crops to reach their wilting point. The farmer ultimately had to apply furrow irrigation to save the crops. Furthermore, when water is unavailable, farmers had to transport water by truck to prevent yield loss.

Farmers have proposed constructing wells to access groundwater for continuous water supply for WSITs. However, this approach was reported to be expensive and challenging. During drought periods in the Khorezm region, groundwater levels can drop to depths of 25 metres, making pumping and extraction costly.

In addition to the water availability, there is also issue with adequate electricity supply to use the WSITs. The technology is associated with energy costs, as the average energy use in drip-irrigated fields is roughly 400 kW/day (Hamidov et al., 2022). Bukhara farmers reported that there are constant interruptions in electricity, further challenging the implementation of the WSITs.

There are also barriers with suitability of the technologies (also suitability of the quality of components of WSITs) with environmental and climatic specificities of the regions. For example, in the Khorezm region, irrigation water is often muddy resulting in frequent clogging of filters of the technologies. Thus, farmers have to change the filters frequently which raises the maintenance costs of the technologies. The high level of natural siltation in Amudarya River requires constant monitoring of drip irrigation tubing and manual removal of silt. The tubing is also not durable enough for hot weather in the regions. Specifically, during the hottest period of the year – referred to as '*chillah*' in the local language – typically in July and August, temperatures can reach up to 50 °C. This period is also the time of high risk of water shortages for crops and significant crop losses (20–40%). Due to the poor durability of tubing under such extreme temperatures, farmers have to replace tubing every season, leading to challenges in the operation and maintenance of drip irrigation systems. The high temperatures during '*chillah*' also reduce the efficiency of the WSIT, particularly with sprinkler irrigation systems, as they are associated with high evaporation rates, resulting in water loss.

Farmers and experts reported that the soil salinity of Khorezm region is another major barrier to adoption of the WSIT as they cannot reduce soil salinity and thus require soil

leaching before planting. Furthermore, shallow groundwater has high levels of salinity in some areas contributing to soil salinity, in line with the results reported by Ibrakhimov et al. (2007) and Akramkhanov et al. (2012). Drip irrigation can be less effective in areas with heavy soil because of their low water retention capacity. This is particularly the case in the Khorezm region (Khamzina et al., 2008).

Although the WSIT perceivably reduce labour during soil preparation and irrigation, they are labour-intensive in regards of installing, removing and reinstalling them in the fields. Due to the poor quality of components, the users of WSIT often face breakage, leading to higher costs and additional issues in maintenance and operation. Furthermore, Khorezm farmers reported an increase in invasive plants and undesirable vegetation, such as weeds, particularly in cotton fields, after implementing these technologies. The limited use of agricultural machinery for cultivation in drip-irrigated fields makes controlling weeds more difficult (Figure 6).

During the FGDs, some farmers showed a lack of trust in policies or authorities. The uncertainty surrounding property rights – since farmers in Uzbekistan have land use rights with leases of up to 49 years – discourages long-term investment and the adoption of new technologies. According to Article 33 of the Law on Farmers (No. 602-I from 30 April 1998), the state is entitled to withdraw a farmer's land use rights if they have negative economic performance for three consecutive years. As a result, farmers who invest in their land risk losing both their investments and the land. Establishing secure property rights or land privatization can incentivize farmers to adopt the technologies.

Proposed ways to overcome barriers and limitations of the implementation of technology

The interviews showed that some experts were sceptical about adoption of the technology package without strong external support. They highlighted that as long as farmers enjoy free or low-cost access to water, investments in WSITs, which involve significant costs, would not be a priority. Additionally, in Bukhara the stakeholder groups recommended reducing interest rates on loans, advocating for interest-free loans to encourage long-term commitment for new technologies.

Subsidies should be reduced and loans interest rates lowered, or, if possible, interest-free loans options should be provided. Because subsidies are free money for farmers, and interest-free loans could make farmers to use the technologies [effectively]. (Bukhara FGD, Bukhara expert opinion)

Similarly, farmers also emphasized the need to reduce loan costs through interest-free loans and extended repayment periods (Figure 5). They called for timely loan allocation by banks. Beyond more favourable financial programmes, participants proposed localizing the technologies by producing them domestically to make it more affordable for farmers. The suggestion to localize production assumes that it will be cheaper locally, which is not always the case.

FGDs highlighted critical needs for the improvement of water accessibility and availability in the regions (Figure 5). Participants emphasized the necessity of constructing wells throughout the regions and modernizing pumping stations to extract groundwater

to enhance water availability. Additionally, building local water storage dams to be used during poor water availability in irrigation canals was suggested. However, stakeholders noted that this solution could result in high water loss – up to 30% – due to evaporation during hot seasons (i.e., *chillah*) and soil absorption (due to sandy soils).

The need for capacity building and skills has clearly become a priority. It has been suggested by the FGDs that when resource users are engaged in social learning processes such as education and capacity building activities, their understanding of the benefits of technology adoption can be improved. When mutual consensus is achieved within a group of resource users and the outcome is institutionalized, this may lead to a sustainable social learning process (Sehring, 2009). Through various workshops and seminars, it may be possible to influence the adoption rate of WSITs.

Discussion

Finally, Khorezm FGDs' participants underlined the key role of research institutions in providing methodological manuals on the usages of the WSITs as well as their suitability to climatic, hydrological and environmental specificities of particular areas, preferably at the district level. Some geographic information system (GIS)-based programmes should be provided so farmers could use the application to determine if the features of their fields (location, water, soils) allow them to implement the technologies, and it would also be helpful to determine how to apply drip irrigation based on those features. These methodological manuals should also include scientific evidence on the advantages and disadvantages of the WSITs at the district level. There is a need to develop a decision-support system and tools, for example, to estimate the crop water demand by utilizing weather data to identify the most suitable WSIT to implement. According to the stakeholders, decision support systems are available for the Fergana Valley region and there are plans to develop similar tools for other regions, including the Khorezm region. Decision support systems should also be available for solar panels installation to address energy costs and energy availability. Here, research institutions could play a crucial role in addressing the above-mentioned needs.

Analytical reflections: operationalizing social learning and prospect theory

This research indicated that farmers are well aware of the existence and benefits of new technologies through knowledge exchange and reflection, which is often considered a significant indicator of occurrence of social learning. This aligns well with the literature on social learning, in which interactions with peer farmers within their social networks, alongside extension services and government agents, serve as the primary source of knowledge about new irrigation technologies and their benefits. Although a number of studies have explored the role of social learning and extension services, as well as their relationship in disseminating information about irrigation technologies among farmers, determining whether farmers acquired this knowledge from extension services or their social networks (e.g., peer farmers) is challenging to measure (Genius et al., 2014).

FGDs further revealed that farmers lack technical information about WSITs, mainly due to inadequate extension services in the study areas. Social learning and extension services are the two main ways through which farmers acquire technical information (Wang et al.,

2020). The complexity of technologies may also contribute to the insufficient technical skills gained through social learning and extension services (Foster & Rosenzweig, 2010). Since WSITs require advanced technical skills, they can be difficult to learn. Therefore, the lack of technical knowledge among farmers may not only be due to the absence of information channels (e.g., social learning) but the inherent complexity of these technologies.

It is important to recognize that social learning does not only positively influence farmers' adoption decisions but can also lead to non-adoption of WSITs (Foster & Rosenzweig, 2010). For example, farmers may learn about the disadvantages of new technologies, such as their negative environmental effects, high costs and lack of suitability for the local area. Farmers also learn about associated risks – important information for a farmers' decision-making – through social learning (Crane-Droesch, 2018). FGDs reveal that farmers are well aware of the risks and challenges associated with adopting WSITs, including their suitability for local environmental and climatic conditions, maintenance issues and potential negative environmental impacts. Even farmers who have not adopted WSITs demonstrated strong awareness of these challenges and risks, suggesting that social learning about the disadvantages of WSITs may have occurred through interactions with peers who have already implemented them.

Risk is a central factor influencing decisions to adopt or not adopt (Chavas & Nauges, 2020). Uncertainty associated with new technologies is often greater compared to old technologies (Marra et al., 2003), making investment in new technologies risky (BenYishay & Mobarak, 2019). Furthermore, the costs associated with new technologies are upfront and immediate, while the returns remain uncertain (Foster & Rosenzweig, 2010). Our study revealed that farmers remain somewhat reluctant to adopt new technologies. This behaviour aligns well with prospect theory, which explains decision-making under risk. When farmers are presented with the potential gains of adopting WSITs (i.e., being in the 'gain domain'), they exhibit risk aversion and prefer the certainty of their traditional methods over the uncertainties associated with new technologies. In other words, farmers have relied on traditional furrow irrigation for many years, accumulating extensive knowledge and skills, whereas new technologies introduce uncertainties regarding maintenance, operation, potential negative effects (e.g., increased weeds) and the need for advanced technical skills. Thus, any changes – adoption of a totally new irrigation technologies – is associated with risks and uncertainties, a tendency known as status quo bias. However, cognitive biases such as risk aversion, uncertainty bias and status quo bias can be shifted when farmers perceive themselves to be in the 'loss domain'. This occurs because people tend to be loss averse according to prospect theory, meaning that losses loom larger than gains. For example, under conditions such as significant yield fluctuations caused by climate change or prolonged droughts, people may become more risk-tolerant (or risk-seeking) and adopt new technologies to maintain their yields and avoid yield loss, indicating loss aversion behaviour. Our study confirmed that Uzbek farmers exhibit loss aversion behaviour, adopting WSITs in response to increasing water scarcity in the region.

These findings go beyond the local context by showing how behavioural and institutional factors – such as risk perception, land tenure insecurity and weak extension services – shape the outcomes of irrigation modernization. The case from Uzbekistan supports evidence from other water-scarce regions that technology adoption depends not only on

technical capacity but also on effective governance and policy support (Hamidov et al., 2024).

In this research, the two complementary theories were used as a conceptual framework to interpret the stakeholders' narratives regarding the challenges associated with technology adoption and the role of information exchange, rather than as a hypothesis for quantitatively testing. Nevertheless, our findings indicate that when resource users are engaged in social learning processes such as education and capacity building activities, their understanding of the benefits of technology adoption can be improved. Furthermore, our results suggest that the resource users are well aware of the benefits of WSITs (e.g., increased yields, water conservation) as well as challenges and risks related to adoption of these technologies, which indicates that there is a social learning process (acquisition of knowledge and technical skills, dissemination of innovation, and building trust and relationships) about new technologies. These were reflected in the theories and in our empirical findings.

Finally, our study adds value by placing the identified (dis)advantages, barriers (risks) and supporting mechanisms of adopting WSITs within the specific institutional and environmental context of Uzbekistan and by examining them through the lenses of prospect theory and social learning theory. To our knowledge, a similar approach involving the two social science theories has not yet been researched in the context of Uzbekistan. Additionally, the FGD settings emphasized how stakeholders collectively interpret, negotiate and adapt these factors through knowledge exchange and reflection, aspects that are less evident in earlier literature.

Policy implications

The Uzbek state has ambitious plans to implement large-scale WSITs in order to use available water resources effectively and increase agricultural production. To this end, they have launched incentive programmes – the Water Resources Development Strategy 2020–2030 and the Water Resources Management and Irrigation Sector Development Programme for 2025–2028 – with the aim of increasing the implementation of WSITs to two million ha by 2030. They also adopted a new policy to develop an additional 218,000 ha of land for irrigated agriculture. Provisional figures suggest that according to national statistics, the area covered by WSITs amounted to 1.9 million ha by the end of 2024. However, due to the weakness of the national verification and monitoring systems, it is difficult to assess the extent to which this has been implemented in practice. Our study indicates that challenges to adoption still remain, such as a lack of technical knowledge among farmers, an absence of extension services, uncertainties surrounding subsidy regulations and land tenure insecurity. The role of social learning, extension services and government agents, including agricultural research organizations, are essential in providing the necessary information and knowledge for farmers about agricultural technologies to reduce risks and uncertainties associated with their adoption.

International experience shows that farmers may perceive investments in new technologies as risky when they experience challenges and uncertainties (BenYishay & Mobarak, 2019). The Uzbek farmers frequently face uncertainty and risk with operation and maintenance of the WSITs due to poor water quality. Other challenges include an inadequate water supply through canals due to poor infrastructure, drought events and

institutional issues (e.g., queue-based water distribution), to name a few. There are also technological externalities (such as increased weeds), increasing costs of inputs and risks regarding suitability of the technologies to the environmental and climatic specificities of the regions. These insights should help open discussions regarding how future policies can be designed and refined to encourage greater adoption of WSITs.

Limitations and future research

We acknowledge some limitations of our study. For example, results may be relevant mostly to the study area due to the small sample size, the selection method may have introduced biases, and irrigation canal maintenance duties may have prevented some farmers from attending. Another limitation was the insufficient information about the socio-economic connections between experts and farmers, which could influence their decision-making processes. Future research should take into consideration these shortcomings.

This research was based on interviews with stakeholders (i.e., focus group discussions) and an analysis of documents concerning WSITs, mainly drip and sprinkler irrigation, which have become an innovative practice among farmers in Uzbekistan. However, other studies also suggest that technologies such as laser levelling and mulching could be considered advanced water-saving methods and warrant further investigation.

The participants reiterated that the implementation of WSIT is an opportunity to acquire new lands for cultivation (irrigation land expansion). Some farmers had acquired some desert land with the help of the WSITs, which could lead to a potential rebound effect whereby farmers adapt their behaviour to offset the expected water savings. Thus, further studies in both regions would be useful for assessing net water savings at the basin or regional level.

Last, but not least, our stakeholder group comprised over 25 participants, including more than 10 farmers, as detailed in the stakeholder composition table in Annex 1. The groups represented various social and geographical contexts within the country (e.g., early adopters, non-adopters and mixed communities). Although based on a limited number of FGDs, the interactive discussions revealed how resource users learn from each other in real time. FGDs indicated knowledge exchange and reflection regarding the benefits and risks of implementing WSITs, as well as enabling participants to respond to and learn from each other during the discussion. These are the core elements of social learning. Having said that though we also acknowledge that involving 25–26 stakeholders may not allow for statistical generalization to the entire country or all farming populations. Our approach was not to target the representativeness, but rather to understand the mechanisms with regard to the challenges in implementing innovative technologies. Thus, future studies should focus on more diverse and larger samples to further validate and quantify the extent to which social learning affects the rate of innovative technology adoption.

Conclusions

We analysed stakeholders' perspectives in implementing WSITs in Uzbekistan. Using prospect theory and social learning theory, we aimed to better understand the underlying

reasons discouraging farmers from adopting new technologies. Our findings suggest that the stakeholders are well aware of the benefits of WSITs (e.g., increased yields, water conservation) as well as challenges and risks related to adoption of WSITs, including high maintenance costs and limited suitability for local conditions. This knowledge indicates there is a social learning process about new technologies. Our findings further indicate risk and uncertainty aversion behaviour of farmers due to the risks and uncertainties associated with adoption of WSITs. This includes high maintenance costs due to physical and economic water scarcity, poor irrigation water quality, limited suitability of technologies to local environmental conditions, and land tenure insecurity. Furthermore, lack of technical skills among farmers, inadequate extension services, along with insufficient research to provide guidance on successful adoption of WSITs based on specific local conditions, further add barriers to technology adoption.

Current policies for the adoption of WSITs are in the initial stages of research and development. There is a need to address it through policy interventions. Thus, the government and development agencies should continue their research and development activities to assess the costs and benefits of adopting these technologies at the farm level, incorporating the consideration of issues related to water use. Overall, the study reveals that by combining behavioural and social learning perspectives with policy and institutional aspects, this study adds to broader discussions on irrigation modernization in water-scarce settings. It shows that promoting adoption requires not only technical improvements but also policy measures that reduce uncertainty and strengthen farmers' confidence to invest.

Finally, we are convinced that the technology package focused upon here offers great potential for contributing to more sustainable water use in Uzbekistan – and on a regional and even global scale, especially in arid and semi-arid zones where water is scarce. To promote adoption of this technology, there is a need for revised policies, such as reducing bank interest rates, improving property rights over land (life-long lease or privatization) and supporting capacity building.

Acknowledgments

The study was financially supported by ICARDA (International Center for Agricultural Research in the Dry Areas). We would like to thank Dr Javlonbek Ishchanov and Dr Sardor Gulamov (both 'TIIAME' NRU) as well as Shakhzoda Umarova (ICARDA) for their support during the design and implementation of focus group discussions. We also appreciate the support that Laura Zara (ZALF) provided in developing the figures. Additionally, Ahmad Hamidov's research for this paper benefited from the German Research Foundation (DFG) through the RebUZ project (GZ: HA 8522/2-2) and from the German Ministry of Education and Research (BMBF) through the SusWEF project (FKZ: 01DK22002). Finally, Akmal Akramkhanov received funding from the CGIAR's Initiative on NEXUS Gains: Realizing Multiple Benefits Across Water, Energy, Food and Ecosystems (Forests, Biodiversity).

Author contribution statement

Ahmad Hamidov: Data collection, Conceptualization, Methodology, Case study contribution, Analysis, Result interpretation and Writing – original draft preparation. **Akmal Akramkhanov:** Data collection, Methodology, Analysis and Result interpretation. **Mukhamadkhan Khamidov:**

Data collection, Case study contribution and Result interpretation. **Umud Juraev:** Data collection, Case study contribution and Result interpretation. **Shakhnoza Abulkosimova:** Conceptualization, Methodology, Analysis and Writing – original draft preparation. **Katharina Helming:** Conceptualization, Analysis, Result interpretation and Writing – reviewing and commenting.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Ahmad Hamidov  <http://orcid.org/0000-0002-6909-0978>
Akmal Akramkhanov  <http://orcid.org/0000-0002-4316-5580>
Mukhamadkhan Khamidov  <http://orcid.org/0000-0002-5513-4933>
Umud Juraev  <http://orcid.org/0000-0002-7828-9524>
Katharina Helming  <http://orcid.org/0000-0002-4379-7377>

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Annex 1: stakeholder composition

Stakeholders in Khorezm	Number of participants
Irrigation and Water Problems Research Institute (SANIIRI)	2
'Tashkent Institute of Irrigation and Agricultural Mechanization Engineers' National Research University ('TIAME') NRU	1
Regional Hydrogeological Ameliorative Expedition	2
Khiva District Water Department	2
Farmers from Gurlan	4
Farmers from Khiva	4
Hydrotechnician - Basin Irrigation System Authority	1

Stakeholders in Bukhara	Number of participants
Bukhara Institute of Natural Resources Management of 'TIAME' NRU	1
Peshku Irrigation System Authority	1
Farmers from Peshku	3
Peshku District Vertical Wells Department	2
Regional Hydrogeological Ameliorative Expedition	2
Bukhara Agrocluster LLC	1

Annex 2: focus group discussion

Schedule and Tasks

Before start: 1. write flipcharts, questions & rules; 2. prepare room for discussion; 3. prepare pinboards.

A. 1st Workshop (farmers)

10:00 Welcome and Introduction.
 Present *schedule* for morning.
 Questions and comments by audience.
 10:10 Housekeeping:
 Present *Rules of the days* – Distribute *name tags*
 10:15 Content:

Present water-saving irrigation technology

10:25 Questions by audience,
 groups formed as people like *or count 1,2,3*.
 10:30 Present first question (Session 1) on flipchart – group work – drawing or writing on cards.
 10:45 End discussion in small groups.
 Facilitator: fix who writes for the group, end of 12 Min. fix who presents for the group.
 10:45 Presentation per group/ discussion per group.
 Overall discussion.
 11:00 Present second question (Session 2) on flipchart.
 Facilitator: fix who writes for the group, end of 12 Min. fix who presents for the group.
 11:15 end discussion in small groups.
 Presentation per group/discussion per group.
 Overall discussion.
 11:30 questions by project team to audience (if time),
 Or flexible 15 minutes buffer or further discussion/ deepening of interesting points.
 11:45 Next steps in project, wrap-up, end.
 12:00 Lunch and discussion.

B. 2nd Workshop (experts)

14:00–16:00 Conduct 2nd workshop with experts (representatives of water organizations).

Housekeeping rules

- Every opinion counts.
- Everybody can make his/her point/ respect and concise.
- What is said in the room stays in the room.
- Keep timing.
- Answer questions.
- Any question is allowed.

Questions: please, draw or write answers on cards

Session 1:

Status quo, level of farmers:

- (1) Is water scarcity a problem in your opinion and for your farm and how do you address it/ how do you suggest to address it?
- (2) Would you adopt the water-saving irrigation technology? Why yes or no?
- (3) For farmers: What are the factors/things that make you adopt the water-saving irrigation technologies? What makes adoption more likely?
- (4) For farmers: what are constraints, hindrances, barriers to adopting the technology?

Session 2:

Status quo:

- (1) What are higher-level issues, contextual aspects that posit constraints, difficulties, hindrances to adoption? e.g., informal rules, costs, benefits expected, uncertainty, maturity of technology, cultural aspects, acceptance, productivity, maintenance, reputation, lack of knowledge/ education, lack of financing, risks involved, lack of policy support, lack of experience, lack of collective action necessary, lack of trust, no time to implement . . .Others?

Future:

- (2) Who could address the barriers to adoption of this and other technical innovations and how should this be done?

Water Consumer Association, BISA, ISA, Ministry, NGOs, policy makers, donors, research . . .