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When water runs dry: How irrigation water scarcity shapes smallholder farmers' mitigation strategies and migration aspiration in developing countries[1]

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Abstract

Increasing water stress, exacerbated by the rising frequency and intensity of droughts, poses a significant threat to smallholder farmers within water-stressed regions. This study examines perceptions of irrigation water scarcity (IWS) among 501 Egyptian smallholder farmers, their intentions to adopt farm-level mitigation strategies, and their migration aspirations. Findings reveal significant heterogeneity in farmers' perceptions of IWS severity, emphasizing the need for tailored interventions addressing distinct challenges across farmer groups. Perceived IWS severity and trust in water-management institutions significantly influence farmers' adoption of farm-level coping strategies. The results further reveal a spectrum of migration aspirations among farmers, ranging from minimal relocation interest to firm commitment. Migration decisions are driven by three factors: resource availability, institutional credibility, and personal risk assessments. Notably, migration outcomes—whether gains or losses—are unevenly distributed and closely linked to observed migration profiles. These findings provide critical insights into the nonlinear IWS-migration nexus, demonstrating how extreme water stress (beyond coping thresholds) triggers committed migration. Overall, the findings underscore the need for dual-track policies: proactively equipping vulnerable farmers with adaptive resources to prevent IWS-induced displacement, while implementing tiered systems to sustain resilient livelihoods or manage inevitable relocation.

Keywords: Water scarcity; Irrigated agriculture; Smallholder farmers; Mitigation; Migration aspirations; Recursive partitioning approach.

JEL classification: O13, Q12, Q15, Q54, R23

1. Introduction

Water is a crucial economic resource for agricultural production and a key driver of rural development, livelihoods, and economic resilience, particularly in regions where irrigation sustains smallholder farming communities (Nakawuka et al., 2018). Agricultural water withdrawals account for 70% of total anthropogenic water use, while irrigated crops contribute 40% of global food production (Pokhrel et al., 2021). Yet, irrigation water resources in many regions around the world are increasingly under pressure

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(Scanlon et al., 2023). Critically, irrigation water scarcity (IWS) arises from a complex interplay of climatic and anthropogenic factors. Climate change impacts, including rising temperatures and changing precipitation patterns, intensify IWS, while growing populations, expanding urbanization, and inefficient water management—such as outdated irrigation infrastructure, over-extraction of groundwater, and unequal water allocation—often amplify these effects and strain water resources (Abu Hatab et al., 2025).

Smallholder farmers are disproportionately vulnerable to IWS due to their reliance on rainfed or minimally irrigated systems, limited access to adaptive technologies, and socioeconomic marginalization (Biswas et al., 2025). Especially in arid and semi-arid environments, where consistent water availability is crucial for livelihoods, evidence reveals that reduced water access severely impacts these farmers (Ariom et al., 2022). The consequences cascade through rural economies, manifesting as lower crop yields, income losses, food insecurity, and heightened vulnerability to shocks (Drechsel et al., 2022). Furthermore, persistent scarcity and droughts exacerbate these pressures, rendering farming unsustainable and pushing farmers toward transformative actions like migration (Bayrak et al., 2023). Such push toward distress migration as smallholder farmers seek alternative livelihood opportunities threatens to reshape the social and economic fabric of rural communities, and contribute to the loss of agricultural labor, and the erosion of traditional farming practices (Leder et al., 2024).

Against this background, this study employs an integrated methodological approach to investigate the critical link between IWS and migration decisions among smallholder farmers in water-stressed regions. Focusing on Egypt's Nile Delta, we analyze data from 501 farmers to: (i) assess farmers' perceptions of IWS severity; (ii) examine their intentions to adopt farm-level mitigation strategies as "proactive" responses; (iii) analyze their migration intentions as "reactive" responses to IWS; and (iv) explore the relationship between farmers' migration intentions and their anticipated economic gains or losses from relocation.

The study is structured as follows. Section 2 reviews the related literature and highlights the study's contributions. Section 3 describes the data collection process and outlines the methodology. Section 4 reports the empirical results. Section 5 interprets and discusses the findings. Finally, Section 6 concludes the paper and draws research and policy implications.

2. Conceptual foundations, literature gaps, and contributions of the study

From a resource-scarcity perspective, "risk" broadly encompasses the uncertainty surrounding potential losses or disruptions in the allocation and utilization of limited resources (Behzadi et al., 2018). In recent decades, agricultural production systems have faced increasingly complex and severe risks that extend far beyond traditional market fluctuations to encompass climate change, environmental degradation, biological threats, and geopolitical conflicts, creating compounded vulnerabilities throughout agrifood systems (Follmann et al., 2024). This expanding risk landscape has stimulated a robust scholarly discourse examining agricultural risk management across agrifood value chains, with particular attention to stakeholder vulnerabilities and institutional responses (Khandelwal et al., 2021). Despite these advances, critical gaps persist in understanding the dimensions of risk perception among resource-constrained smallholders facing IWS - a lacuna this study addresses.

A notable limitation in existing research is its predominant focus on risk avoidance strategies, which, while valuable, may not fully address the root causes of risks or their broader impacts. In addition, previous studies on agricultural risk in developing countries have predominantly focused on farmers' response strategies and risk management approaches, while paying comparatively less attention to thoroughly identifying and measuring perceived risks themselves. This represents a significant oversight, as the literature on adapting to and mitigating environmental hazards consistently shows that individual responses are shaped by how they perceive risk (Arbuckle et al., 2015). Since "perception" is socially constructed and communicated, variations in personal experiences and beliefs about the existence and characteristics of a given hazard, expectations about technology, and trust in institutions, all influence individuals' awareness and understanding of hazards, and ultimately guide their decisions and actions (or inaction) in response (Slovic, 2016). In this context, perceived severity operates as the fundamental dimension of risk analysis and management, reflecting the subjective evaluation of a risk's potential consequences (Wachinger et al., 2013). For instance, farmers who perceive IWS as severely threatening to their livelihoods (high perceived severity) are more likely to view it as a salient risk requiring immediate action, whereas those who downplay its impacts may underestimate the risk (Grothmann & Patt, 2005). Thus, the limited research that does examine risk perception often fails to systematically connect these perceptions to actual coping strategies, creating a disjointed understanding of the risk-adaptation continuum.

Our study addresses this critical gap by explicitly examining the risk-adaptation nexus: the dynamic interplay between how farmers perceive IWS risks and how they ultimately respond to these threats. Specifically, we adopt a resource-based approach by examining the sources of risk and their perceived severity consequences on smallholder farmers' agricultural activities and livelihood. That is, drawing from organizational theory, we conceptualize the farm as an organizational unit and apply the notion of organizational capability—defined here as a farm's "capacity to deploy resources for a desired end result" (Helfat & Lieberman, 2002)**.** This approach allows us for identifying, analyzing, and managing risks that stem from the availability, accessibility, and sustainability of critical resources (e.g. IWS) essential for a system or an activity (e.g. farming businesses). This also allows us to assess how different resource dimensions—financial, physical, human, and social assets—shape smallholder farmers' risk perception and adaptive responses to IWS. In other words, unlike broader financial or market-based risk analyses, a resource-based approach delves into the physical, environmental, and socio-economic factors that directly influence water availability and accessibility. This is particularly important for smallholder farmers, who often rely heavily on irrigation for crop production and are disproportionately affected by IWS due to limited resource and adaptive capacity.

An equally critical gap emerges in the literature on farmers' adaptation behaviours in response to IWS in developing regions is the conceptually problematic dichotomy between incremental and transformational responses. Existing studies routinely examine farm-level adaptations (e.g., crop diversification) and livelihood transformations (e.g., migration) as mutually exclusive categories, neglecting their functional interdependence in real-world adaptation pathways. These two strands have, therefore, largely evolved in isolation from each other, leaving a fragmented understanding of the full spectrum of adaptation processes. For instance, research on farmers' response to IWS, particularly in the MENA region, has focused on incremental adaptations, which aim to enhance resilience while allowing farmers to continue agricultural livelihoods within the same environmental and economic context. Comparatively, less research has been undertaken to address migration as a coping strategy for IWS. Evidence however shows that when local adaptation options are insufficient or inaccessible, migration often emerges as a coping mechanism (Epstein et al., 2022; Makondo & Thomas, 2021), although IWS is often not the sole reason driving migration from water-scarce areas (Borgomeo et al., 2021). In this study we consider both proactive adaptation measures (incremental farm-level) and reactive adaptation measures (that is, migration) to better understand how micro-level adjustments and macro-level transformations interact and reinforce one another. This integrated approach offers critical value, recognizing that farm-level strategies are profoundly shaped by institutional and policy contexts (Del Castillo Múnera et al., 2019), and that transformational adaptations often emerge from the aggregation of incremental farmer decisions. Examining both adaptation types within a unified framework can reveal the complex interplay of factors, including risk perception, resource availability, and external constraints, that determine when farmers prioritize incremental improvements versus transformative change. This may also provide policymakers with deeper insights for simultaneously supporting on-farm resilience through improved water management, and sustainable migration pathways as a viable adaptation option when local conditions become untenable.

A third critical gap in the existing literature, particularly evident in MENA region studies where our case study is situated, is the insufficient attention to behavioral and psychological factors influencing risk perception and adaptation decision-making (Abu Hatab et al., 2025). The predominant focus of current research has been on technological and engineering solutions, such as improving irrigation efficiency, desalination, water recycling, and water management systems and efficiency measures (Mahmoud & Gan, 2019; Sayed et al., 2023). However, existing studies largely overlook how cognitive biases, risk attitudes, and social-psychological processes mediate farmers' interpretation of IWS risks and their subsequent behavioral responses. This neglect is especially problematic in MENA agricultural systems, where cultural values, traditional knowledge systems, and collective memory of environmental shocks may uniquely shape risk appraisal processes. Incorporating psycho-behavioral dimensions should enrich our understanding of why farmers may resist adopting new technologies, prioritize certain coping strategies, or perceive risks differently despite similar external conditions (Nasiri et al., 2024). Our study is the first to provide empirical evidence that considers a range of psycho-behavioural variables, including perceptions, intentions, psychological distance and trust in service providers. With this, we contribute to a more comprehensive understanding of farmers' risk perception and adaptive behaviours, which is essential for designing interventions that align with farmers' attitudes, beliefs, and decision-making processes, ensuring that solutions are not only technically sound but also socially and culturally acceptable (Shojaei-Miandoragh et al., 2020).

A fourth critical gap in the literature is the lack of systematic investigation into how anticipated gains and losses from migration shape farmers' migration aspirations. While recent studies have examined migration drivers such as economic incentives or environmental push factors (Borgomeo et al., 2021; Epstein et al., 2022), few have empirically linked farmers' subjective evaluations of migration outcomes (anticipated gains or losses) to their actual migration intentions. This oversight is significant, as behavioral theories, such as the Prospect Theory (Kahneman & Tversky, 1979), posit that decision-making under risk is driven not by objective outcomes but by *perceived* gains and losses. Our study addresses this gap by developing an anticipated gain/loss index, which measures farmers' cost-benefit assessments of migration and maps them to empirically derived migration clusters of the surveyed farmers. This approach advances the migration-environment literature by treating anticipated outcomes as *dynamic decision weights* rather than static determinants, offering a nuanced framework for targeting interventions based on farmers' risk-reward calculus.

3. Data

3.1. Study context and survey area

Egypt serves as an especially compelling case for the study of smallholder farmers' perceptions and response to IWS, since it mirrors many of the IWS challenges encountered by many other developing countries (Zayed & Abdelmoaty, 2024). Located in the Middle East and North Africa (MENA) region, one of the most water-scare regions globally, IWS has become an escalating concern for Egyptian agriculture that poses significant challenges to farmers, agricultural production systems, and food security (Christoforidou et al., 2023). Specifically, while Egypt relies heavily on the Nile River for more than 95% of its freshwater needs, the country faces mounting pressure from climate change, upstream water developments, population growth, and inefficient water management, all of which are exacerbating IWS (Fouad et al., 2023). Like many other countries in the region, whose rural economies mainly depend on agricultural products, intensive irrigated agriculture is responsible for over 80% of freshwater consumption. In particular, smallholder farmers, who constitute the backbone of Egypt's agricultural sector, are particularly vulnerable due to their dependence on irrigation and limited adaptive capacity (Zdruli & Zucca, 2023). Despite these IWS challenges, research on how Egyptian farmers perceive and respond to water scarcity remains limited in the social science literature, with most studies focusing on technical interventions rather than on farmers' decision-making processes (Abu Hatab et al., 2025).

Fayoum Governorate occupies a stretch of Egypt's Western Desert to the west of the Nile Valley, lying between latitudes 29° 10′ and 29° 30′ N and longitudes 30° 20′ and 31° 10′ E (State Information Service, 2023). Administratively, it includes six centers—Senorus, Itsa, Tamia, Ebshoway, Yousef El Sadeq, and Fayoum—and spans an area of approximately 6,068 km². As of 2023, Fayoum's population is estimated at about four million people. Notably, 71% of the governorate's residents live in rural settings and are primarily engaged in agricultural activities (Kotb et al., 2024).

The Governorate has approximately 400,000 feddans of cultivated land, with an average farm size of 1.7 feddans (0.71 hectares) (Directorate of Agriculture in Fayoum Governorate, 2021). Agricultural activities are predominantly carried out by smallholder farmers, who cultivate a wide range of crops, including horticultural products, medicinal and aromatic plants, as well as essential field crops such as wheat, cotton, rice, and maize. Due to the region's arid conditions, irrigation is indispensable, relying mainly on Nile water distributed through an extensive network of canals (Kotb et al., 2024). Nevertheless, challenges such as outdated water infrastructure, inefficient irrigation methods, institutional constraints, and unauthorized water extraction by farmers have contributed to a chronic water shortage (Omar & Moussa, 2016).

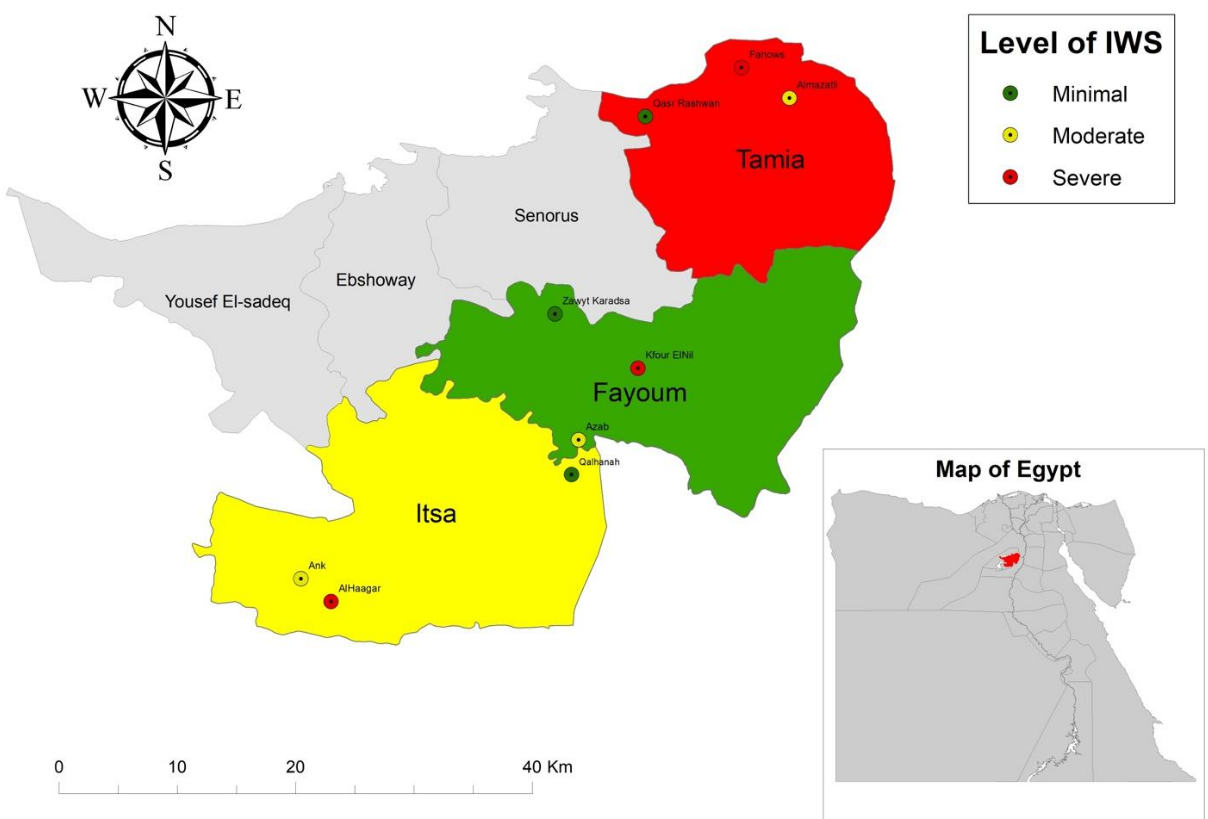

Figure 1. Map of Fayoum Governorate and study areas

In recent years, persistent IWS has led to significant social and economic consequences, including reduced agricultural productivity, declining rural incomes, and increased food insecurity (Abu Hatab et al., 2025). In reaction to these challenges, a growing number of residents are migrating—either internally to major urban centers like Cairo and Giza or internationally to regions such as the Gulf and Europe—in search of better economic opportunities. This outmigration has resulted in notable demographic changes and labor shortages in farming communities, posing a threat to the sustainability of rural areas in the long term (World Bank, 2020).

3.2. Survey design, sampling strategy, and participants

The study was exempt by default from requiring ethical approval under both the Swedish and Egyptian university regulations, as it does not involve the collection or handling of any sensitive personal information. Informed consent was obtained from all participants. Before the interviews started, farmers were provided with a brief overview of the study objectives and were asked to give their informed consent for participation.

Guided by recent literature on farmers' perceptions and response to climate change and environmental stressors in developing countries, the research team developed a questionnaire through a multi-stakeholder engagement process, involving smallholder farmers, researchers from Fayoum University, water-user associations, and government provincial authorities of the Ministry of Agriculture and Land Reclamation and the Ministry of Water Resources and Irrigation. The questionnaire was translated into Arabic and reviewed by and academic and a practitioner in the field of water-resource management. A pre-test of the questionnaire was administrated to two selected farmers in each study area to ensure question appropriateness, logical flow, and respondent comprehension. The pilot study influenced the refinement of the final questionnaire, which comprised both structured and few open-ended questions (Supplementary Material 1). The final questionnaire consisted of several sections, which collected information about farmers' sociodemographic characteristics, farming and irrigation system characteristics, perception of IWS and its effects on farm business and household livelihood; farmers' intentions to adopt coping strategies to address perceived IWS risks; farmers' psychological distance to IWS; migration aspirations and anticipated gains from migration; and farmers' perceptions and trust in water-management institutions.

The field survey was conducted in three administrative divisions (centers) of Fayoum Governorate (Figure 1). Based on extensive stakeholder consultations, these three areas were identified as representative of the challenges of IWS and indicative of the farming realities for the entire governorate. These are: *Fayoum*, *Tamia*, and *Itsa*. Within each of these administrative divisions, three villages were selected to reflect varying degrees of IWS from minimal to severe based on stakeholders' insights and governorate's agricultural statistical information (Figure 1).

A total sample size of 501 participants was included in the study. To enhance representativeness, the sampling was designed to correspondingly reflect the distribution of cultivated land across the three municipalities (Table A1 in Supplementary Material 2). A priori power analysis was conducted using G*Power 3.1 software (Faul et al., 2009) to determine the minimum sample size required to detect medium-sized effects (Cohen's $d = 0.5$) with 80% power at a significance level of $\alpha = 0.05$ for the planned statistical tests. The analysis indicated that our sample of 501 provides adequate statistical power. This sample size is robust enough to provide reliable insights and detect meaningful effects and relationships within the data and support generalizable conclusions. This sampling approach ensured that the responses efficiently represent the challenges and insights of smallholder farmers regarding water scarcity and their coping strategies, and that the findings are both meaningful and applicable to the wider farming community in Fayoum.

Interviews took place from June to August 2024, with each interview lasting approximately 40 minutes. Table A2 in Supplementary Material 2 provides a description of the 501 farmers participated in the survey. With an overwhelming majority being male (97.8%), most farmers are in their mid-to-late career stages. Educational attainment varies widely; nearly half (45.1%) have no formal education or only limited primary schooling, whereas about 38.3% hold a technical qualification or a university degree. Farming experience is typically substantial, with 89.0% reporting more than 15 years of experience. The vast majority (92.8%) are married, and over half live in households comprising five to seven members.

Regarding income sources, slightly over half depend solely on farm-related earnings, while 44.7% have off-farm or non-farm income. Agriculture remains a key income contributor, with 42.3% indicating it accounts for 75–100% of total household income. Meanwhile, 89.6% receive government subsidies, but only 5.2% report support from NGOs.

Farm holdings are generally modest in size, although they range widely: approximately 16.6% cultivate 12 kirats or fewer, while 28.7% farm more than 48 kirats. Most farmers (63.1%) own their land outright, whereas 36.9% either rent or sharecrop. The main crop is frequently wheat (66.1% list it as their primary), followed by maize, clover, and sugar beet. Many farmers (55.7%) primarily produce for sale but also retain a portion for household use.

Irrigation and water management are critical issues: 90.2% of respondents rely on surface water, and the predominant method is flood irrigation (over 98% combined, with or without pumps). Farm location along irrigation canals varies, with about a quarter at the canal beginning and two-fifths near the end. The cost of water and canal maintenance remains a concern: while 36.5% note stable water bills, 30.9% report increased costs, and 27.3% see them as significantly high. Overall, the data highlight a predominantly experienced, with moderate farm sizes, varied cropping systems, and pressing irrigation challenges.

4. Methods

This study employed a multi-step analytical approach consisting of six sequential steps, which are summarized in the following steps:

4.1. Measuring farmers' perceived severity of irrigation water scarcity

To assess perceived IWS severity, 23 items were included in the survey (See Section 4 in the in Supplementary Material 1). Items were carefully selected based on a thorough review of the relevant literature on the impacts of IWS on smallholder farmers and rural communities in LMICs. Consultations with local experts and stakeholders were also conducted to ensure the relevance of the items to the specific context of study and that each item added unique value to the analysis. Furthermore, as part of the pre-analysis, we conducted an analysis among the items to identify any significant correlations that might lead to redundancy or inflation of perceived risks. The results indicated that while some items exhibited moderate correlations, the majority were sufficiently distinct to warrant their inclusion as separate sources of perceived IWS severity.

While previous studies tend to focus on traditional dimensions of risk (likelihood and severity), our analysis provides a more dynamic and actionable understanding of risks, particularly for time-sensitive challenges like IWS by accounting for the "immediacy" of perceived risks. A risk with high immediacy, such as an impending drought, will be perceived differently and would require urgent interventions compared to a long-term risk like gradual soil degradation. This approach is especially useful for smallholder farmers, who often operate with limited resources and need to prioritize risks that demand immediate attention. Specifically, perceived IWS risks were assessed by integrating a temporal dimension (*i.e.*, delay or immediacy of impact) into the traditional model of perceived risks (*i.e.*, severity and likelihood of exposure) (Abu Hatab & Lagerkvist, 2024). Respondents assessed each item from a tabular format (see Section 3 in Supplementary Material 2). Specifically, they were asked to "*review the following potential impacts on your farm business and household livelihood in relation to how you envisage the situation of irrigation water shortage (IWS) in your area*. Please give your most honest opinion on their anticipated impacts as well as on how likely you expect these issues are to occur in the short to long run".

- *Severity*: This dimension was aimed to capture the intensity of the perceived consequences of IWS on the respondent's farm business and household wellbeing. Respondents were asked to rate the severity of each item on a scale ranging from "minimal" (1), indicating a negligible impact, to "moderate" (2), suggesting a noticeable but manageable effect, and "severe" (3), reflecting a significant and potentially disruptive impact.
- *Likelihood*: This dimension focused on the probability that respondents anticipated a specific impact item would occur and affect their farm business and household livelihood. The response options ranged from "very unlikely" (1), indicating a low probability of occurrence, to "quite unlikely" (2), "neither likely nor unlikely" (3), "quite likely" (4), and "very likely" (5), representing a high probability.
- *Immediacy*: This dimension captured the anticipated timeframe within which respondents expected a specific impact item to affect their farm business and household livelihood. The response options were structured to reflect varying degrees of urgency, ranging from "now or soon (within 3 months)" (1), representing an immediate or very near-term concern, to "In more than 2 years" (5), representing the longest-term concern, where the impact was perceived as a distant possibility rather than an immediate threat. It should be noted that during the data analysis, the original immediacy categories were recoded reversely to allow for a more intuitive interpretation of the data, where higher scores indicated greater urgency, so that "Now or soon (within 3 months)" was assigned the highest score (5), while "In more than 2 years" was assigned the lowest score (1).

Based on responses to these dimensions of IWS impacts, a multiplicative score was computed for each respondent by integrating the three key dimensions (severity, likelihood, and immediacy). The formula applied was [($severity \times likelihood \times immediacy$)/0.75], which standardized item scores to a range of [0, 100]. Individual item scores were then averaged across all items. This approach allowed for a weighted assessment of the perceived severity of IWS, and provided a comprehensive and quantifiable representation of the overall severity of IWS as perceived by the respondents, facilitating further analysis and comparison across different groups or clusters of respondents.

4.2. Segmenting farmers based on perceived IWS severity

A *k*-means clustering approach was employed to group the surveyed smallholder farmers into clusters that exhibited maximal similarity in perceived IWS severity within each cluster while maximizing dissimilarities between clusters. The analysis was performed using the R package 'factoextra v1.0.7' in conjunction with the 'cluster v2.1.4' package (Maechler et al., 2024) within the R programming environment (R Core Team, 2021). To determine the optimal number of clusters, two approaches were compared: (i) evaluating the relationship between the number of clusters and the total within-cluster sum of squares, and (ii) assessing the number of clusters against the gap statistic (Tibshirani et al., 2001). The gap statistic was calculated using 50 Monte Carlo (bootstrap) samples to ensure robustness in identifying the most appropriate cluster solution. Differences between the clusters identified by the *k*-means clustering were analyzed by comparing the average scores for each item across the clusters to reveal the distinct patterns in how each cluster perceived IWS severity

4.3.Investigating smallholder farmers' intentions to adopt mitigation strategies

The next step of the data analysis examined the relationship between cluster membership for IWS severity, and farmers' intentions to adopt mitigation strategies. Institutional trust and psychological distance were introduced as potential moderators of this relationship.

To assess smallholder farmers' intentions to take action, they were asked, *"How do you intend to address the potential impacts of IWS on your farm business and household livelihood?"* The questionnaire included 13 items (see Section 5 in Supplementary Material 1), with responses recorded on a 5-point Likert scale from "completely disagree" to "completely agree." A principal component analysis (PCA) was conducted to examine the dimensionality of the intention items, resulting in two distinct constructs, denoted *Intention: action and engagement* (*Intent1)* and *Intention: investment* (*Intent2)*. Indices for each construct were created by as the sum product of item scores and their respective PCA loadings divided by the sum of PCA loadings (see Table A4 in Supplementary Material 2). *Intent1* (10 items) captured broader intentions related to water-saving practices, such as using water-saving technologies, changing cropping patterns, and collaborating with neighboring farms to implement collective water management strategies. *Intent2* (3 items) focused specifically on investment-related intentions, such as investing in water-saving technologies, and seeking funding (e.g., loans) to implement improve irrigation infrastructure to mitigate the effects of IWS on the farm.

Using these two indices (*Intent1* and *Intent2*), we examined the relationship between perceived IWS severity and farmers' intentions to adopt mitigation strategies. Farmers' psychological distance in relation to IWS was measured using two items that were designed to deconstruct psychological distance into its core dimensions (spatial, social, temporal, and hypothetical) based on established theoretical frameworks (Trope & Liberman, 2010). Respondents were asked to rate their agreement with specific statements on a bipolar 7-point Likert scale, where 1 indicated strong disagreement and 7 indicated strong agreement (See Section 6 in Supplementary material 1). Institutional trust was measured as a PCA-based index derived from a set of corresponding items in the questionnaire (see Section 9 in Supplementary Material 1). The moderation analysis was conducted using the "PROCESS" procedure (Hayes, 2017) in SPSS Version 4.2.

4.4. Clustering farmers based on their migration aspirations

A *k*-means clustering approach was once again utilized to group the surveyed farmers based on their responses to migration-related items in the survey (see Section 7 in Supplementary Material 1). The selection of these items was informed by the framework developed by Carling and Mjelva (2021), which offers a structured approach to deconstructing and analyzing survey questions on migration aspirations. This framework breaks down the formulation of such questions into a set of abstract components, including consideration, preference, willingness, necessity, planning, intention, expectation, returning, and likelihood of migration. To illustrate this deconstruction, consider the example question: "*Considering the anticipated IWS situation on your farm, do you have any intention of going to live or work in another place than your current village in the next two year?*" Questions like this typically consist of two key elements: a "mindset" and an "action" (Van Dalen & Henkens, 2013). The mindset refers to the thoughts, feelings, attitudes, or judgments being inquired about—in this case, the intention to migrate. The action represents the specific behavior or outcome the mindset refers to—here, "in the next two years." This mindset–action pairing mirrors the attitude–object relationship commonly used in public opinion research. Notably, items 7.3 and 7.9 were excluded from the analysis as they were conditional on responses to other items (7.2 and 7.1–8, respectively). The clustering analysis was carried out using the same R packages employed for the clustering of perceived IWS impacts.

4.5. Examining the role of psychological predictors in explaining cluster membership for migration intentions

A binary recursive partitioning approach using ordinal linear regression was employed (Hill et al., 2006) to examine how behavioral factors relate to migration cluster membership. This approach was chosen for its ability to handle the complexity of model specification from a large set of explanatory variables (Seibold et al., 2019). The approach works by recursively splitting the data into subsets based on the values of predictor variables, creating a decision tree that partitions the data into increasingly homogeneous groups. Each split is determined by the variable that best explains the variation in cluster membership, ensuring that the resulting model captures the most significant predictors. In this analysis, we incorporated the following psychological predictors as explanatory variables for cluster membership: perceived IWS clusters, intentions to adopt mitigation strategies, psychological distance, and institutional trust.

To identify sub-groups of smallholder farmers while considering the distributional properties of explanatory variables, the partitioning process of the included explanatory variables follows three steps (Hothorn et al., 2006). First, a global null hypothesis is tested using Bonferroni-adjusted p-values to ensure unbiased variable selection. If rejected, the explanatory variable with the strongest association (lowest p-value) is selected for a binary split. Second, the optimal cut point is determined through permutation tests, dividing the sample into two subgroups. Finally, the process repeats recursively until no further statistically significant splits are found. A key advantage of this tree-based method is its automatic variable selection, ensuring only the most relevant explanatory variables are included. The recursive partitioning model was estimated using the Ctree module in the R package partykit v.1.2–16 (Hothorn & Zeileis, 2015), implemented in R programming language (R Core Team, 2021), with a significance level of 0.05.

4.6. Investigating the relationship between the migration intentions and the anticipated gains or losses from migration

A Principal Component Analysis (PCA) was performed involving the 5 statements included in the questionnaire to gather information regarding the surveyed farmers' anticipated gains or losses from migration (See Section 8 of the questionnaire in Supplementary Document 1). KMO measure of sampling adequacy was 0.755, indicating suitability for PCA, and Bartlett's test of sphericity was significant ($\chi^2 = 483.410$, $p < .001$), confirming that the variables were correlated sufficiently for PCA. The first principal component explained 73.93% of the total variance, suggesting a strong unidimensional structure. The remaining components explained minimal variance, supporting the use of a single component. All items loaded highly on Component 1 (loadings ranged from 0.802 to 0.895), confirming their contribution to a single latent factor. Next, an index for the anticipated gain/loss from migration was constructed (AGL Index) as a weighted sum of the 5 item scores, where weights were derived from the PCA loadings. The sum was normalized by dividing by the sum of the component loadings. The AGL index has a Mean of 5.629, Median of 5.858, and a Standard Deviation of 0.928, indicating a moderate-to-high perceived gain from migration. The index ranged from 1.80 (minimum) to 6.44 (maximum), showing variability across respondents. Finally, two non-parametric tests were used to examine differences in the AGL Index across the 5 clusters obtained from the prior migration intentions analysis. The Kruskal-Wallis test was used to test for overall differences in AGL Index distributions across clusters (Kruskal & Wallis, 1952), and the Jonckheere-Terpstra Test, which was used to explore the ordered differences (e.g., whether AGL Index scores increased/decreased monotonically across clusters (Gibbons & Chakraborti, 2014).

5. Results

5.1. Clusters of farmers based on perceived IWS severity

The cluster analysis of smallholder farmers' perceptions of IWS impacts revealed three distinct clusters (See Figure A1 in Supplementary Material 2). Table A3 in Supplementary Material 2 presents average risk scores for each of the 23 items by the three clusters identified. The following is a brief description of each cluster:

- **Cluster 1: Highly vulnerable and risk-aware farmers (n = 144, 29%):** This group consists of farmers who perceive IWS as a severe and immediate threat to their agricultural productivity and household livelihoods. Their risk perceptions are notably high, with average scores exceeding 90 for 12 out of the 23 items. These farmers are particularly concerned about risks that directly impact their economic stability and environmental sustainability. For instance, they strongly believe that IWS will degrade soil fertility, leading to reduced productivity (item 22), and diminish net profits by increasing input costs while reducing yields (item 8). They also perceive IWS as a driver of soil salinity and erosion (item 23), which will necessitate additional soil maintenance measures (item 10) and reduce the quality of their agricultural produce (item 3). Furthermore, they worry that delayed planting dates due to IWS (item 13) will prevent them from capitalizing on high market prices at the beginning of the season. These high-risk perceptions reflect both immediate financial strain and long-term sustainability challenges, making this group the most vulnerable due to their acute awareness of these threats and limited capacity to mitigate them.
- **Cluster 2: Adaptable and low-risk farmers (n = 128, 25%)**: Farmers in this cluster perceive IWS risks as minimal and manageable, with mean scores for all risks consistently in the single digits. Their low-risk perception suggests that they view IWS as a challenge that can be effectively addressed with existing strategies and resources.
- **Cluster 3: Resilient and moderately concerned farmers (n = 229, 46%):** Farmers in this cluster acknowledge the risks associated with IWS but perceive them as moderate rather than severe, with none of their mean risk scored exceeding 68.5. Their concerns span both economic and environmental dimensions, with key risks including reduced agricultural yields (item 1), increased production costs (item 4), and soil degradation due to elevated salinity levels (item 23). They also recognize that IWS may delay planting dates (item 13), preventing them from taking advantage of high market prices early in the season, and necessitate leaving portions of their farms uncultivated to ensure water availability for other crops (item 11). Despite these challenges, this group demonstrates resilience and certain ability to implement coping mechanisms.

5.2. Relationship between perceived IWS risks and farmers' intentions to adopt coping strategies

Table 1 presents the results of examining the relationship between perceived IWS severity and farmers' intentions to adopt mitigation strategies, with institutional trust and psychological distance included as moderators. For the first intention measure (*Intent 1*), the analysis reveals significant positive effects for both Severity Cluster 1 (highest perceived severity; $\beta = 1.33$, 95% CI [0.58;2.08], $t = 3.48$, $p < 0.001$) and Severity Cluster 3 (moderate severity; $\beta = 0.79$, 95% CI [0.07;1.64], $t = 1.80$, $p = 0.072$) compared to the reference Cluster 2, indicating that farmers perceiving greater IWS risks show stronger intentions to adopt water-saving practices.

Institutional trust demonstrates a robust positive relationship with *Intent 1* ($\beta = 0.26$, 95% CI [0.13;0.38], $t = 4.08$, $p < 0.001$), suggesting that farmers with greater confidence in water management institutions are more motivated to implement conservation measures. However, psychological distance shows no significant association, and none of the interaction terms reach statistical significance, indicating these relationships hold regardless of farmers' psychological distance to the risk or their institutional trust levels.

For the second intention measure (*Intent 2*), only institutional trust emerges as a significant predictor (β = 0.22, 95% CI [0.08;0.37], t = 2.98, p < 0.05), demonstrating that trust positively influences farmers' willingness to invest in water-saving technologies. The severity clusters show mixed but non-significant effects, while psychological distance shows an insignificant negative association. As with *Intent 1,* no interaction effects achieve statistical significance.

Table 1. Regression coefficients, standard errors, confidence intervals and model summary information for the moderated mediated models for behavioral intentions

Variables	Dependent variable							
	Intent 1				*Intent 2*			
	Coeff.	*SE*	*CI*[b]	*p*	*Coeff.*	*SE*	*CI*[b]	*p*
Constant	2.63	0.34	1.96;3.30	<0.001	2.60	0.39	1.82;3.37	<0.001
Severity:								
Severity cluster 1 (SC1)[a]	**1.33**	0.38	0.58;2.08	0.005	-0.37	0.45	-1.24;0.51	0.411
Severity cluster 3 (SC3)[a]	**0.79**	0.44	0.07;1.64	0.072	0.32	0.51	-0.68;1.32	0.528
Psychological distance (PD)	0.06	0.05	0.03;0.16	0.203	-0.08	0.06	-0.19;0.03	0.150
SC1×PD	-0.05	0.09	-0.23;0.13	0.574	-0.10	0.11	-0.31;0.11	0.332
SC3×PD	-0.11	0.09	-0.28;0.07	0.240	-0.06	0.11	-0.27;0.14	0.549
Institutional Trust (IT)	**0.26**	0.06	0.13;0.38	0.001	**0.22**	0.07	0.08;0.37	0.003
SC1×IT	-0.18	0.11	-0.41;0.04	0.102	-0.20	0.13	-0.46;0.06	0.135
SC3×IT	-0.40	0.13	-0.40;0.12	0.284	-0.20	0.15	-0.50;0.10	0.195
	$R^2 = 0.0813$				$R^2 = 0.112$			
	$F(8, 492) = 5.446, p < 0.001$				$F(8, 492) = 7.724, p < 0.001$			

Note: [a] The variable 'severity cluster' is categorical with cluster 2 as reference category, [b] lower and upper limits of the 95% Confidence Interval.

5.3.Farmer clusters based on migration aspirations

Based on surveyed responses regarding migration aspirations, five distinct clusters were identified (See Figure A2 in Supplementary Material 2). The following sub-sections provide brief descriptions of the cluster profiles presented in Table 2.

- **C1: Predominantly non-migratory with conditional openness (n = 28)**: Farmers in this cluster show minimal interest in migration, with their responses are mostly near zero, indicating little consideration, preference, willingness, or necessity for migration. The only slight deviation is in the "Willing" response (score = 1.04), suggesting a marginal openness to migration under optimal conditions, though overall, these farmers remain largely non-migratory.
- **C2: Contemplative but unprepared migrants (n = 37)**: These farmers exhibit moderate levels of consideration, preference, willingness, and necessity for migration (scores ranging from 0.67 to 0.89). However, their scores for planning (0.19) and preparation (0.08) are very low, indicating that while they are considering migration, they are not taking concrete steps. The relatively high likelihood of moving (3.24) is accompanied by an intention to return (0.95), suggesting a conditional approach to migration.

- **C3: Definite non-migrant farmers (n = 327)**: As the largest group, farmers in this cluster exhibit very low scores on all migration-related measures, with most responses near zero. They show little interest in migration, and even though "Willing" and "Likelihood" scores are slightly higher, they remain low compared to other clusters, indicating a general disengagement from the idea of migration.
- **C4: Aspiring migrants with strong intent (n = 58)**: This cluster is characterized by very high scores across all dimensions of migration aspiration, including consideration, preference, willingness, and necessity. High scores in planning and preparation suggest these farmers are actively getting ready to move. The likelihood of moving is high (4.00), and there is no intention to return (score = 1.00), reflecting a strong intent to migrate permanently.

Table 2. Cluster profiles and means by each cluster for each of the 10 items related to migration aspirations by the identified clusters of the farmers surveyed

Aspects of migration intentions	Migration clusters (cluster size)				
	C1(n=28)	C2 (n=37)	C3 (n=327)	C4 (n=58)	C5 (n=51)
Consideration	0	0.89	0.015	0.98	1
Preference	0	0.7	0	0.96	1
Willingness	0	0.73	0.01	0.98	1
Necessity	0.04	0.68	0	1	1
Planning	0	0.19	0.01	0.96	0.98
Preparation	0	0.08	0.01	0.93	0.86
Intention	0	0.57	0.01	1	1
Expectation	0.07	0.62	0.05	1	0.94
Willing	1.04	1.19	1.08	2.64	3.43
Return	0	0.95	0.95	1	0
Likelihood	1.21	3.24	3.24	4	4.33

Cluster size is measured as the number of famers belonging to each cluster.
Supplementary Material 1 for more details regarding the questions identifying each of the 10 items relating to migration aspirations.

- **C5: Committed migrants with no return (n = 51)**: Farmers in this group are fully committed to migration, with the highest scores across all migration-related questions. Many responses are at the maximum (1.00), with high levels of planning (0.98) and preparation (0.86). The likelihood of moving is the highest among all clusters (4.33), and there is no intention to return (score = 0), indicating a definitive and permanent migration decision.

To explore and validate the relationship between perceived IWS severity clusters and migration intention clusters, we conducted a cross-tabulation analysis with follow-up predictive accuracy tests (See Table A5 in Supplementary Material 2). The analysis revealed a robust and statistically significant association between farmers' perceived IWS severity clusters and their migration intention clusters ($\chi^2(8) = 217.34$, $p < 0.001$), with a moderate-to-strong effect size (Cramer's V = 0.47). The predictive accuracy analysis demonstrated distinct adaptation pathways: farmers in the high-risk IWS cluster (Cluster I) were 9.4 times more likely than expected to fall into the strongly migrant-aspiring group (Cluster 4), while low-risk perceivers (Cluster II) showed an 85.6% probability of remaining definite non-migrants (Cluster 3). Moderate-risk farmers (Cluster III) exhibited bifurcated tendencies, with 40.6% correctly classified as non-migrants but a significant minority ($z = +3.8$) transitioning to committed migrants (Cluster 5).

These results provide compelling evidence that farmers' risk perceptions of IWS systematically predict their migration intentions, with clear severity gradients emerging across the adaptation spectrum. The overall classification accuracy of 71.3% confirms that IWS perceived severity serves as a reliable indicator of potential migration behavior, highlighting the importance of incorporating risk perception measures in climate adaptation planning and policy interventions. The findings particularly underscore how high-risk perceivers demonstrate a strong propensity toward transformative adaptation through migration, while low-risk farmers maintain agricultural livelihoods, suggesting the need for differentiated policy approaches based on farmers' risk profiles.

5.4. Determinants of cluster membership for migration aspirations using behavioural variables

Figure 2 presents the recursive partitioning model linking the five identified migration aspiration clusters to key behavioral variables (perception of IWS severity, intentions, psychological distance, and institutional trust). The results show that perceived severity of IWS is the primary factor splitting the surveyed farmers into two grouped: one containing the *adaptable and low-risk farmers* (Cluster 2), and the other including both *highly vulnerable and risk-aware farmers* (Cluster 1) and *resilient, moderately concerned farmers* (Cluster 3).

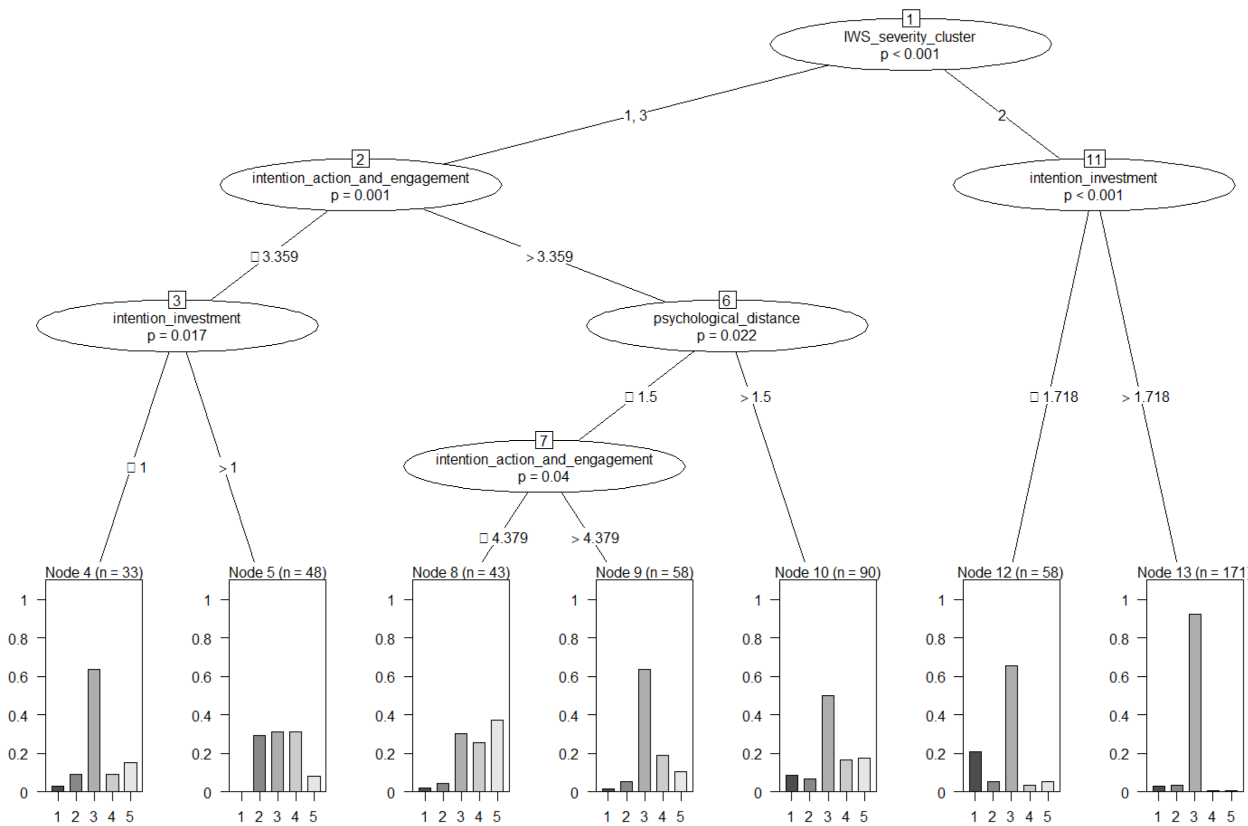

Figure 2. Ordinal regression for the five clusters for migration aspirations with binary recursive partitioning using behavioural variables as explanatory variables.

Note: End-nodes shows the probability of cluster membership for migration aspiration (C1 to C5) conditional on the distributional properties of the explanatory variables with the largest statistical association with the dependent variable based on Bonferroni-adjusted p-values. The explanatory variables that were used in the analysis are: perception of IWS severity, intention to adopt water-saving practices, intention to invest in water-saving technologies and seek funding to improve irrigation infrastructure to mitigate the effects of IWS, psychological distance, and institutional trust. Statistically significant covariates in the figure are: IWS severity clusters, *Intent action and engagement* (intention to adopt water-saving practices), *Intent* investment (intention to invest in water-saving technologies and seek funding to improve irrigation infrastructure to mitigate the effects of IWS), and *psychological distance*.

Within the *adaptable and low-risk* sub-sample, the intention to invest in water-saving technologies and seek funding for irrigation infrastructure (Intent 2) emerges as the most influential factor. Farmers with stronger investment intentions (Node 13, n = 171) largely belong to the *definite non-migrant cluster* (C3), while those with weaker investment intentions (Node 12, n = 58) are also in the *definite non-migrant cluster* (C3), with a smaller proportion in the cluster of *predominantly non-migratory farmers* who maintain a conditional openness to migration (C1).

Conversely, the sub-sample comprising highly vulnerable and risk-aware farmers (Cluster 1) and resilient, moderately concerned farmers (Cluster 3) shows more nuanced dynamics. We find that the intention to adopt water-saving practices (Intent 1) splits them into two branches. Among those with stronger intentions, psychological distance plays a crucial role: farmers with a longer distance are more likely to be *definite non-migrants* (C3) (Node 10, n=90). However, farmers with shorter psychological distance are further divided into two groups based on their intentions to intention to adopt water-saving practices (Intent 1) into two sub-groups: farmers with stronger intentions are likely to be *definite non-migrants* (C3) (Node 9, n=58), whereas those with weaker intentions appear in the clusters of committed migrants with no return (C5), aspiring migrants with strong intent (C4), and to less extent in the definite non-migrants cluster (C3) (Node 8, n=43).

For farmers with weaker water-saving intentions (far-left of branch of tree), subsequent divergence occurs based on investment intentions (Intent 2). Notably, stronger investment intentions predict migration-oriented clusters (Node 5, n= 48, mainly farmers in C4 and C5), possibly reflecting either resource accumulation enabling relocation, or transitional investments before farm abandonment. Conversely, weaker investment intentions associate with non-migration (Node 4: n= 33, mainly farmers in C3), suggesting either entrenched traditionalism or capacity constraints. This bifurcation reveals that investment intentions operate differently depending on baseline conservation behavior.

5.5. The relationship between the migration intentions and anticipated gains or losses from migration

The results of the Kruskal-Wallis test for the overall differences in AGL Index distributions across the 5 farmer clusters based on their migration intentions are presented in Table A6 in Supplementary Material 2. The results show a significant omnibus effect ($\chi^2(2) = 22.851$, $p < .001$), rejecting the null hypothesis of equal distributions. With regard to the results of the Jonckheere-Terpstra Test, Table M in Supplementary Material 2 show a significant trend (JT = 3924.000, $p < .001$), indicating a systematic ordering of AGL Index scores across migration clusters. In addition, all pairwise differences were significant ($p \leq .013$). Overall, the results of these tests confirm that farmers' anticipated gains from migration systematically align with their level of commitment to relocate. For instance, farmers who firmly opposed to migration (Cluster 3) perceived minimal benefits from relocation, whereas hesitant farmers (Cluster 2) who were merely contemplating migration showed modestly higher expectations of positive outcomes, though these remained significantly lower than those of farmers actively preparing to move (Cluster 4). The most striking difference emerged between tentative considerers and the fully committed migrants (Cluster 5), who anticipated the greatest gains, a pattern that held consistently across all comparisons.

6. Discussion and policy implications

Our empirical findings provide empirical evidence regarding how smallholder farmers' perceived severity under IWS shape their proactive and reactive mitigation pathways. The following sections highlight and discuss our main findings:

- **Farmers perceive a diverse range of IWS severity with varying levels of vulnerability**

The clustering results based on farmers' perceived IWS risks underscore the diversity in their perceived severity of IWS, as well as their varying levels of vulnerability and resilience. Specifically, we identify three distinct clusters. Farmers in the first cluster were acutely aware of the severe economic and environmental impacts of IWS, but lack the capacity to mitigate these risks effectively. Prior research indicates that while smallholder farmers often perceive greater severity from direct exposure to water shortages, constraints such as limited financial resources and inadequate institutional support hinder their adoption of resilient agricultural practices, increasing their vulnerability to ongoing and future water stress (Ariom et al., 2022; Biswas et al., 2025).

The second cluster comprised farmers who perceive IWS risks as minimal and manageable, which is likely due to their higher socio-economic standing or stronger institutional connections that facilitate resource access, adoption of water-saving techniques, and implementation of diversified cropping strategies. The third cluster, recognizing moderate IWS risks, demonstrates notable resilience, often attributed to openness to alternative income sources and diversified farming practices. This balanced approach enables them to sustain productivity and mitigate the adverse effects of water scarcity (Tesfahunegn & Gebru, 2022).

Understanding these cluster-specific differences in vulnerability to IWS impacts is essential for designing targeted interventions to promote sustainable water management and agricultural resilience. As noted by Berhanu et al. (2024), policies and support mechanisms that are informed by farmers' distinct constraints and capabilities can more effectively enhance resilience and alleviate the impacts of environmental changes.

- **Perceived severity of IWS and trust in water-management institutions shape farmers' intentions to adopt coping strategies**

The results of the moderated mediated models for behavioral intentions (Table 1) reveal an interesting distinction in how farmers respond to perceived IWS severity. While their intention to adopt short-term mitigation strategies, such as changing cropping systems or implementing water-saving practices (*Intent 1*), is influenced by their perception of water scarcity, the same perception does not significantly drive their willingness to make long-term investments in irrigation systems or other farm-level infrastructure (*Intent 2*). One potential explanation for these findings stems from the Theory of Planned Behavior, which holds that individuals' decisions are shaped by their attitudes, social norms, and perceived control (Ajzen, 1991). Short-term adaptations, like altering crop choices or adopting water-efficient techniques, are often viewed as low-cost, reversible, and within the farmer's immediate control. By contrast, long-term investments, such as upgrading irrigation infrastructure, demand substantial financial commitment, long planning horizons, and involve greater uncertainty regarding future returns. Consequently, farmers may perceive less control over these larger-scale investments, reducing the influence of perceived IWS severity on their choices and decision-making. Another perspective draws on the concept of "temporal discounting", where individuals tend to undervalue future benefits in favor of smaller, sooner rewards, even if long-term solutions ultimately prove more beneficial and efficient (Schattman et al., 2021).

In addition to personal risk assessments, the results reveal that trust in institutional frameworks serves as a catalyst for farmers' behavioral intentions for both short-term and long-term adaptations (Table 1). These findings corroborate a number of recent studies (Dong et al., 2023), suggesting that when farmers perceive water management institutions as reliable and competent, they are more likely to view conservation advisories as legitimate, invest in long-term adaptive measures (e.g., drip irrigation, soil moisture monitoring), and engage in collective action, such as community-based water allocation or shared infrastructure maintenance From a policy perspective, strengthening institutional performance and transparency may therefore accelerate technology adoption, especially if coupled with programs explicitly targeting farmers who recognize themselves as vulnerable. Future research can further investigate how these relationships evolve over time and whether targeted interventions, like awareness campaigns or trust-building initiatives, might amplify the effect of perceived risk on farmers' willingness to invest in adaptive measures.

Notably, the results show that psychological distance does not act as a moderator between perceived IWS severity and the adoption of proactive measures. One way to interpret this finding is through Construal Level Theory, which posits that individuals perceive distant events more abstractly and immediate events more concretely (Yazdanpanah et al., 2023). In many cases, an individual's psychological distance to a threat (e.g., spatial, temporal, or social distance) can affect how they weigh the severity and likelihood of that threat. However, when farmers face pressing and tangible water scarcity, the situation is already "psychologically near." This makes abstract dimensions of distance less influential, because the threat is concretely felt rather than hypothetically considered. Thus, the salience of local conditions might diminish the role of psychological distance, as farmers who regularly encounter water shortages do not need abstract cues or external reminders to prioritize adaptations; the threat is already integrated into their daily realities.

• **A continuum of migration aspirations from marginal openness to definitive commitment**

The results reveal a spectrum of migration aspirations among the surveyed farmers, spanning from minimal interest in relocating to resolute commitment to leave. At one end of this continuum are farmers who remain firmly opposed to moving, demonstrating a conscious choice to stay despite environmental pressures. Such voluntary immobility often stems from stable local conditions, strong familial and community ties, or a personal preference to maintain existing social networks and cultural practices (Farbotko et al., 2020). In addition, another cluster of farmers show little inclination to migrate, but may remain marginally open if IWS conditions deteriorate. Their hesitation aligns with existing research on place attachment, where strong social, cultural, or economic ties can outweigh push factors like IWS (Berg, 2020). In some cases, structural constraints, including the high costs of migration, fear of uncertainty, or lack of viable economic options, intensify their reluctance. This pattern reflects the concept of involuntary immobility (Carling, 2002), wherein individuals may wish to move but are prevented from doing so by systemic barriers.

On the other extreme are farmers who exhibit strong aspirations to migrate or have already decided to leave with no plans of return. This echoes broader research on rural–urban migration, which finds that deteriorating environmental conditions, limited economic opportunities, and the anticipation of better prospects elsewhere are key drivers of migration (Stoler et al., 2022). As noted by Wrathall and Van Den Hoek (2022), these factors often incentivize farmers and rural dwellers to pursue livelihoods in urban or peri-urban areas, hoping to improve their overall socioeconomic status.

Somewhere in the middle of this spectrum, a notable cohort of farmers remains unprepared to migrate despite contemplating it. Their indecision highlights the role of uncertainty and barriers, be they financial, informational, or institutional, that hinder concrete action. This phenomenon aligns with discussions in migration literature suggesting that while push factors may spur interest in relocation, a lack of resources or clear pathways can leave individuals in a state of indecision rather than prompting definitive moves (Carling & Schewel, 2020). In addition, theoretical frameworks like the aspiration–capability model (De Haas, 2021) help explain how aspirations alone are insufficient for migration unless combined with the means (financial, social, and informational) to realize them.

Collectively, these divergent responses urge a recalibration of policy frameworks to account for the non-linear decision-making processes uncovered here. Specifically, the bifurcation of high-risk farmers into migrants (C4–C5) and persistent non-migrants (C3) suggests that uniform interventions may fail to address subgroup-specific needs. While earlier studies treated incremental and transformational adaptations as mutually exclusive, our analysis reveals their dynamic interplay, with investment intentions paradoxically predicting both persistence (Node 4) and migration (Node 5). This challenges the linear assumption of 'accumulation-then-adaptation' prevalent in the literature.

Addressing migration aspirations, therefore, requires a multi-tiered approach tailored to the varying levels of commitment. For those only marginally considering migration, strategies such as improving local infrastructure, diversifying livelihood options, and offering financial or technical support may help mitigate push factors. Meanwhile, policies addressing committed migrants could focus on facilitating organized migration pathways, while supporting rural communities in managing the outflow of labor and the social changes that ensue. Future research could expand on these insights by exploring how sudden shocks, *i.e.* Environmental, economic, or otherwise, shift farmers' positions along this continuum and influence both their aspirations and capabilities to relocate.

- **Interplay of perceived water scarcity, adaptation intentions, and migration decisions**

The findings indicate that farmers' perceptions of IWS severity are pivotal in shaping their migration aspirations, with additional influences from their intentions to invest in water-saving measures, their level of trust in water-related institutions, and the psychological distance they assign to these risks. On one hand, farmers who view water scarcity as relatively manageable and express readiness to invest in irrigation improvements tend to remain non-migratory, suggesting that a sense of resilience backed by tangible resource commitments can limit the push toward relocation. On the other hand, farmers identified as more vulnerable or moderately concerned about IWS risks reveal more complex migration pathways, often hinging on how urgently they perceive these threats and how much confidence they have in institutions to manage them effectively.

These results resonate with broader literature on livelihood strategies under environmental stress, which highlights the role of resource availability, institutional credibility, and personal risk assessments in determining whether people choose to remain in place or migrate (Hoffmann et al., 2022). In addition, they suggest that effective adaptation strategies should not only enhance material resources (e.g., access to credit or irrigation infrastructure) but also address behavioral and cognitive barriers. Policies that improve farmers' risk awareness, foster trust in adaptation interventions, and reduce psychological distance from future IWS risks can complement traditional resilience-building measures. Therefore, integrating both structural (resource-based) and cognitive (psycho-behavioral) factors provides a more holistic framework for designing interventions that support both farm-level adaptation and migration as viable responses to IWS and environmental stresses.

- **Anticipated gains or losses are closely linked to observed migration profiles**

The results showed significant differences in anticipated gains or losses from migration across the five migration intention clusters. For instance, the low scores of the *Predominantly Non-Migratory with Conditional Openness* farmers (C1) on the AGL reflect limited perceived benefits from migration. Their marginal openness to migration suggests that even slight improvements in perceived gains (e.g., economic incentives or reduced risks) could influence their decisions.

The moderate AGL scores for the *Contemplative but Unprepared Migrants* (C2) align with their ambivalence, moderate consideration but low preparation. This indicates that their conditional approach and lack of planning may stem from uncertainty about migration outcomes. Interestingly, the cluster of *Definite Non-Migrant Farmers* (C3) has the lowest scores on the index, consistent with their disinterest in migration. Their resistance to migration suggests deep-rooted preferences for local livelihoods. However, the high Index scores for the cluster of *Aspiring Migrants with Strong Intent* (C4) match their active preparation and permanent intent (no return = 1.00). Their optimism about migration likely drives planning efforts. Finally, the highest index scores for the *Committed Migrants with No Return* cluster

(C5) reflect their absolute confidence in migration benefits, as their maximalist stance (no return = 0) signals irreversible displacement. Overall, this graded relationship between AGL and migration profiles demonstrate that as farmers progress from passive consideration to concrete preparation and finally to resolute commitment, their expectations of migration benefits intensify proportionally. The findings suggest also that farmers' relocation decisions follow a rational calculus, where the transition from adaptation to abandonment occurs when anticipated gains outweigh perceived losses.

These findings closely resonate with the Protection Motivation Theory (PMT) (Rogers, 1975), which posits that individuals adopt protective behaviors based on threat appraisal (severity and vulnerability of a threat) and coping appraisal (their sense of efficacy and expected benefits of a new location). High threat and coping appraisals increase the likelihood of protective actions, such as migration in response to water scarcity, while low appraisals may lead to inaction or denial (Marikyan & Papagiannidis, 2023). Therefore, farmers with high migration intentions likely perceive water scarcity as a severe and immediate threat while also believing that migration offers a viable solution. Conversely, non-migrants may either underestimate the threat or doubt their ability to successfully relocate, leading to inaction. These findings further reinforce that policy interventions should be tailored to different farmer profiles. Future research could further explore these dynamics by examining how farmers' perceptions evolve over time, particularly after exposure to real-world migration outcomes. In addition, studies could investigate the role of social networks in shaping migration intentions, as peer influences may strengthen or weaken perceived threats and coping abilities.

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