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The impact of social networks on water security in rice production in central Vietnam

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Abstract
This study assesses the impact of social network participation, particularly among women, the elderly, farmers, and cooperative organizations, on water security in rice cultivation in Central Vietnam. Data were collected from over 600 rice farms in the region using a convenience sampling method to assess the influence of these networks, and Propensity score matching (PSM) was employed to address selection bias. The findings reveal that membership in cooperative organizations enhances water security in rice farming, while participation in women's organizations and diverse social networks may reduce it. An instrumental variables approach also indicates that involvement in multiple organizations reduces water security. The findings suggest that the government should promote cooperative organizations, which effectively improve water security, while addressing challenges posed by women's organizations and diverse social networks.

Keywords Social network, Membership, Water management, Rice production, Vietnam

1 Introduction

Agricultural production is pivotal in the Vietnamese economy, contributing significantly to GDP and employment. As of recent years, agriculture accounted for approximately 18.4% of Vietnam's GDP, with over 70% of the national labor force engaged in this sector [1]. This sector not only provides livelihoods for a substantial portion of the population but also underpins food security and rural development. The predominance of small-scale farmers, who represent more than 80% of agricultural producers, highlights the importance of agriculture in sustaining rural economies and communities, [2, 3].

Rice, in particular, is a cornerstone of Vietnam's agricultural landscape, contributing to about 24% of GDP and generating approximately 20% of the country's export revenues [1, 3]. However, the rice sector in Vietnam faces numerous challenges that threaten its sustainability and productivity. These challenges stem from environmental, economic, and social factors, which collectively impact the livelihoods of millions of farmers and the overall stability of rice production [4–6]. More importantly, the rice sector faces significant challenges related to water security, which is critical for sustaining production and ensuring food security.

One of the primary challenges is the increasing variability in water supply due to climate change. The extreme weather events disrupt the regular irrigation schedules essential for rice cultivation, leading to reduced yields and increased vulnerability for farmers [7]. In addition to climate-related challenges, the reliance on domestic water reservoirs is insufficient to meet the demands of rice cultivation, particularly in regions like the Red River Delta and the Central Coast [8]. Moreover, the overuse of chemical fertilizers and pesticides in rice farming has led to water quality degradation, which further complicates water security issues [8].

In 2022, Central Vietnam's total rice cultivation area reached approximately 1.185 million hectares, accounting for about 17% of Vietnam's total rice production area, positioning it as the second-largest rice-producing region in the country. Specifically, the provinces of Thanh Hoa, Nghe An, Ha Tinh, and Binh Thuan are particularly notable, each contributing over 120 thousand hectares to the cultivated land, which underscores their critical role in the national rice supply chain. In addition, those provinces have the largest area of rice production in Central Vietnam . However, this region is not without its challenges; it grapples with significant water scarcity issues that threaten the sustainability of rice production [9–11]. Water scarcity can adversely affect crop yields and, consequently, food security, making it imperative to explore adaptive strategies that can mitigate these impacts. In 2023, significant drought conditions adversely affected rice output in Central Vietnam, with in serious agricultural and economic consequences. Reports show that in Nghe An Province, more than 3,000 hectares of rice fields remained uncultivated due to water shortages, leading to substantial drops in rice output, with losses surpassing 17,000 tons compared to the prior year [12]. Ha Tinh Province faced significant difficulties, with over 13,000 hectares affected by water constraints, resulting in crop failures across more than 5,000 hectares [12]. Drought conditions have intensified due to diminished rainfall, increased temperatures, and reservoir depletion during critical growing periods for rice harvests [13].

Social networks can play a crucial role in ensuring water security, particularly in agricultural contexts where water management is essential for sustaining crop production and food security. Social networks are defined by the relationships and interactions that form between individuals within a community or group. Membership in various organizations, such as professional associations, civic groups, or cooperative societies, expands one's network by introducing new connections and opportunities for collaboration [14]. Engaging in multiple organizations can enhance individuals' access to resources, information, and support, further solidifying their position within a network [11]. The integration of social networks into water governance frameworks can enhance collaboration, knowledge sharing, and resource management among stakeholders, thereby addressing the multifaceted challenges associated with water security [15]. Effective community organization and collaborative networks enhance local capacities for resource management [16]. In particular, cooperative organizations have emerged as a practical and impactful mechanism to promote water security in rice production. These organizations coordinate shared irrigation schedules, maintain infrastructure, and ensure equitable distribution of water resources. Their participatory governance structures empower farmers to jointly develop water management practices jointly, thereby fostering accountability and reducing conflicts [17]. Additionally, cooperatives facilitate the pooling of financial and human resources for investment in irrigation systems, water-saving technologies, and climate-resilient agricultural practices [18]. By leveraging collective bargaining power, cooperatives also improve access to external support, such as government subsidies and development aid for water infrastructure [19]. Furthermore, the establishment of participatory governance frameworks that include farmers and local communities can lead to more equitable and effective water management. By involving local stakeholders in decision-making processes, social networks can ensure that water management strategies are inclusive and responsive to the needs of all community members, ultimately enhancing water security [20].

However, one of the key challenges posed by social networks is the potential for unequal power dynamics within them. Such unequal power relations can lead to inequitable access to water resources, especially in systems where certain households or groups dominate the water distribution network. This inequity may result in conflicts and tensions within communities, undermining collective efforts to manage water resources effectively [21]. Additionally, social networks can sometimes reinforce unsustainable practices. For example, if influential members of a social network advocate for practices that prioritize short-term gains over long-term sustainability, other members might feel pressured to conform, even when those practices harm water resources [22]. Moreover, social networks can create a false sense of security about water availability. When communities heavily rely on informal networks for information about water resources, they may lack access to accurate data regarding water scarcity or quality issues. This scarcity of reliable information can lead to poor decision-making and inadequate responses to water crises, as communities may underestimate the severity of their water challenges [23].

The relationship between social networks and water security in rice production is complex and multifaceted. Understanding the relationship is crucial not only for Vietnam but also for other countries facing similar challenges in agricultural water management. By examining this relationship, the study can provide insights into how social capital influences water management, helping policymakers and agricultural stakeholders develop strategies that strengthen community collaboration and improve water governance. This study aims to determine the effect of social networks (membership in women, elders, farmers, and cooperative organizations) on water security in rice production in Central Vietnam. The findings provide distinctiveness and profundity to the relationship between social networks and water security in rice cultivation.

This study provides new and context-specific insights into the complicated relationship between social network engagement and water security in rice farming in Central Vietnam. This area is particularly sensitive to climate-induced water stress. Unlike previous studies that assumed social capital was always beneficial, this study disaggregates the benefits of various types of social organizations, including women's, farmers', elders', and cooperative groups, revealing that not all social networks contribute equally to water security. The study addresses both observable and unobservable biases using Propensity Score Matching (PSM) and Instrumental Variable (IV) approaches, thereby improving the validity of its causal assertions. The discovery that cooperative membership considerably improves water security. In contrast, women's organization membership and diversified network engagement may weaken it, calling into question long-held ideas and having important consequences for rural governance. This comprehensive approach adds to the growing body of research on climate resilience, agricultural water management, and social capital by emphasizing the distinct roles of local institutions in resource control.

2 Conceptual framework

In this study, the conceptual framework is grounded in established theoretical perspectives, notably resilience thinking and climate-smart agriculture [24, 25]. It also draws from the social capital literature, particularly the role of organizational membership in facilitating adaptive behavior and collective resource management, as emphasized by Pretty [24]. These theoretical ideas helped integrate social, economic, managerial, and community aspects into the framework, enabling a comprehensive understanding of how households address water security issues in smallholder rice farming.

The conceptual framework (Fig. 1) provides the determinants of water security in rice production at the household level. It integrates multiple layers of analysis, encompassing household socio-economic characteristics, social capital through organizational membership, and broader institutional interventions. This multi-dimensional approach reflects the complexity of achieving water security in smallholder agricultural systems.

At the core of the framework are the household and rice farm characteristics, which represent internal capabilities and resource endowments. Variables such as the age, gender, and educational attainment of the household head are included to capture differences in decision-making, adaptive capacity, and access to information. In addition, economic attributes,namely, access to credit, savings, wealth status, and involvement in non-farm activities,play a critical role in determining a household's ability to invest in water-saving technologies, irrigation infrastructure, or alternative coping strategies. The area of rice and total agricultural land reflects production scale and water demand, while the number of family members may influence available labor and household water needs. These factors collectively shape a household's vulnerability and adaptive capacity concerning water security.

The second dimension of the framework highlights the influence of social networks, operationalized through household membership in various community-based

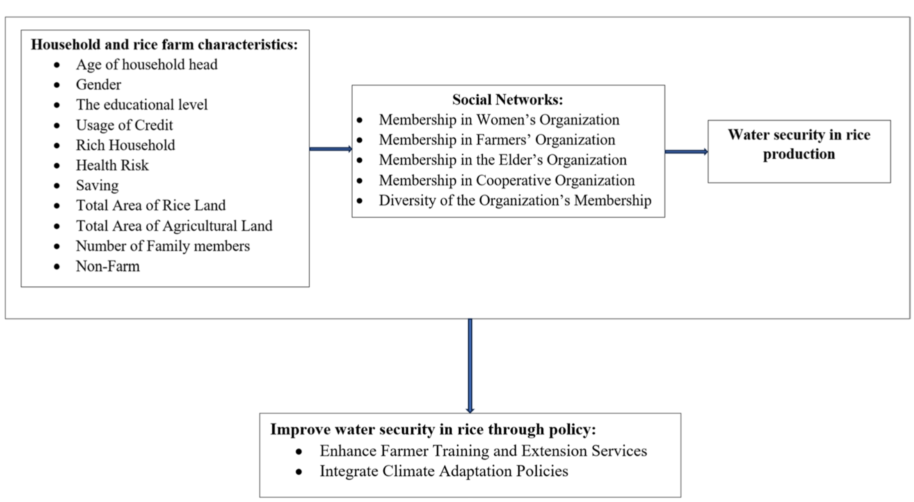

Fig. 1 Conceptual framework for the relationship between social networks and water security in rice production

organizations such as women's groups, farmer associations, elder organizations, and cooperatives. These networks serve as channels for the dissemination of information, coordination of water access, and collective negotiation with institutions. Particularly, the diversity of organizational membership is posited to strengthen households' resilience by increasing exposure to different types of support, thereby enhancing their ability to cope with water-related stress. This aligns with the literature on social capital, which emphasizes that access to institutions and group-based learning can significantly mediate household responses to resource constraints [24]. Based on the study's analysis, certain policy interventions have been implemented to enhance water security in rice production.

In summary, this framework conceptualizes water security as a function of multi-scalar interactions between household-level characteristics, social network engagement, and institutional interventions. This theoretical orientation is consistent with resilience thinking and climate-smart agriculture principles, which emphasize cross-level coordination and inclusive governance in response to environmental risks [24]. The framework provides a foundation for empirical analysis and policy assessment, offering insights for targeted interventions that promote water security and sustainable rice production in climate-sensitive regions such as Central Vietnam.

3 Methodology

3.1 Data source

By utilizing convenient data collection, this study gathers data on rice production in Central Vietnam to investigate the correlation between social networks and water security, highlighting the region's agricultural importance and its associated challenges. The study utilized 2023 statistical data from the Vietnamese government to select four provinces with the largest rice production areas: Thanh Hoa, Nghe An, Ha Tinh, and Binh Thuan. Within each province, the district with the highest rice production area was chosen. Subsequently, the community with the largest rice production area in each district was selected for data collection from rice-cultivating households. In 2024, the study surveyed the Central region to gather information on household rice production, focusing on data from the 2023 season. A total of 600 household heads engaged in rice farming participated in the interviews, with 238 from Thanh Hoa, 127 from Nghe An, 120 from Binh Thuan, and 115 from Ha Tinh (Fig. 2). Each household head was asked whether their household had sufficient water for agricultural production.

3.2 Propensity score matching (PSM)

This study evaluates the impact of membership in each organization on water security in rice production, focusing on calculating the Average Treatment Effect on the Treated (ATT). To achieve this, the study compares the outcomes of households participating in each social organization with those not. The primary challenge lies in the inability to directly observe outcomes without membership in a social organization commonly referred to as the counterfactual. Addressing this issue is central to the study.

Selecting a valid control group that has not joined a social organization is essential to conducting a robust impact evaluation [26]. Randomized experimental designs typically involve comparing outcomes between treatment and control groups; however, this study does not employ random assignment. Instead, participating in a social organization

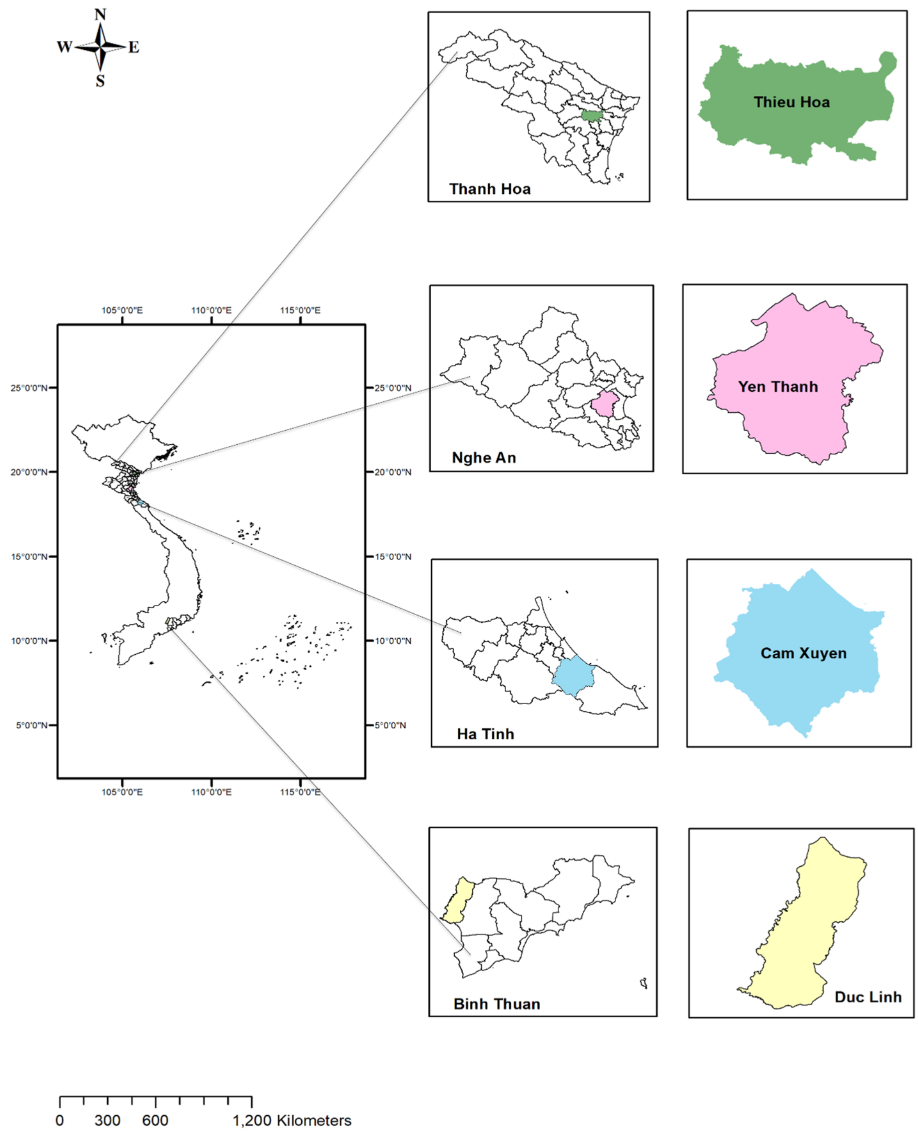

Fig. 2 A map of the study area

results from individual choice, potentially introducing self-selection bias. In the absence of randomized experiments, non-experimental methods such as Instrumental Variable (IV), Propensity Score Matching (PSM), Difference-in-Differences (DID), or a combination of PSM and DID become critical for estimating ATT [3, 27]. In this study, Propensity Score Matching (PSM) is adopted as a more suitable method to mitigate selection bias [28].

PSM involves estimating the probability of households joining a social organization using a logit model that accounts for observable factors. This process generates propensity scores for both the treated group (joint) and the control group (non-joint). The logit model is expressed as follows:

$$P(X) = logit(D = 1) = \alpha + \beta * X$$

Here, D represents the treatment status (membership in a social organization), and X includes observable characteristics unaffected by the treatment. Before conducting matching, two critical conditions must be satisfied. First, the common support region must be established, ensuring overlap in propensity scores between joint and non-joint. Households with propensity scores outside the common support region (e.g., scores higher than the maximum or lower than the minimum of the control group) are excluded to avoid biased comparisons. This step ensures robust estimates by restricting matching to comparable households and improving match quality.

Second, the balancing property test must be met [29]. This test requires that the distribution of observable characteristics (X variables) be identical regardless of treatment status within groups with similar propensity scores. Although no universal standard exists for acceptable levels of imbalance, standardized differences between 10 and 25% are commonly recommended.

In the final step, members are matched with non-members based on similar propensity scores. The study employed a nearest-neighbor matching algorithm with a caliper size of 0.1 standard deviations of the logit of the propensity score. Households with propensity scores outside the common support region were excluded from the analysis. The formula for estimating ATT using the PSM method, as proposed by Becker and Ichino [29], is as follows:

$$ATT^{PSM} = E((Y_{iA} \mid D = 1, P(X))) - E((Y_{iN} \mid D = 0, P(X)))$$

Here, ATT measures the impact of membership in each social organization, such as women, farmers, elders, and cooperative organizations, on observed outcomes such as water security. D denotes the treatment status (joint), Y_{iA} and Y_{iN} represent outcomes for membership and non-membership, respectively, and P(X) is the propensity score based on observed covariates. The difference in outcomes between membership and matched non-membership provides the ATT estimate.

Using the Propensity Score Matching (PSM) method in STATA version 17, the study divided households into two groups with similar characteristics based on their membership or non-membership in social organizations, including women's, farmers', elderly, and cooperative organizations. The study compares the outcomes, specifically the Average Treatment Effect on the Treated (ATT), between households participating in each organization and those that do not. Table 7 presents the ATT results before and after applying PSM.

3.3 Instrumental variable method

Propensity Score Matching (PSM) is a widely used statistical technique in observational studies to reduce bias from confounding variables by creating comparable treated and untreated groups. However, achieving covariate balance between these groups remains challenging, as different PSM methods can produce varying treatment effect estimates and may not always ensure optimal balance. Additionally, PSM's effectiveness can be limited by unobserved factors, such as income levels or community cohesion, which may simultaneously influence social networks and water security in rice production.

To address these limitations and account for unobserved confounding and endogeneity, this study employs the Instrumental Variable (IV) method to robustly estimate the effect of social networks on water security in rice production. IV analysis is a powerful statistical approach for identifying causal relationships in the absence of controlled experiments, particularly when unobservable confounders are present. By leveraging the strengths of IV analysis, the study provides more reliable results regarding the impact of social networks on water security. The study assumed that water security can be a function of social networks and other explanatory variables, as given in the equation below:

$$WS_i = b_0 + \mu_i SN_i + b_i X_i + \xi_i \quad (1)$$

where WS_i is the water security of rice farm i. SN_i refers to membership in each organization. X_i is a vector of household and rice farm characteristics. ξ_i is the error term. The application of the OLS method for Eq. (1) may result in biased and inconsistent estimates; therefore, the method of instrumental variables (IV) should be employed to provide consistent estimators. The study uses external instrumental variables such as the distance from home to the community center. The instrument chosen, such as distance from the household to the community center, is theorized to influence the likelihood of social network participation due to its effect on access to information, community engagement opportunities, and mobility constraints [14]. Households located farther away may face higher transaction costs in participating in organizational activities. However, this distance should not directly affect water security outcomes, assuming that water access is managed at the community or irrigation system level rather than on household proximity. Therefore, it meets the exclusion restriction condition, provided spatial variation in water infrastructure is adequately controlled.

The study employs the F-statistic from the Cragg-Donald Wald F-statistic to assess the validity of the instrumental variable (Table 1). The findings from the initial stage of regressions reveal that nearly all F-statistics are near 10, such as 5.435, 6.940, and 28.154 (Appendix 1), suggesting that the study did not encounter issues with weak instruments. The findings validated the rejection of the null hypothesis for exogenous regressors at the 10% significance level, suggesting that social networks are endogenous (Table 8).

4 Results

Table 2 presents the sample's descriptive statistics, providing insights into various household characteristics. The average household shows a moderate level of water security, with 56.3% having secure access. Membership in social or economic organizations varies, with 49.7% being members of women's associations and 33.8% belonging to farmer associations. In contrast, other associations, such as elder or cooperative organizations, have significantly lower participation rates. The average household head is approximately 49 years old, predominantly male (52.8%), and has a low educational level, averaging just over three years of schooling. Access to credit appears relatively high (mean of 0.557), suggesting some variability in responses. Only 18.3% of households are classified as "rich," and 29.2% face health risks. The average household size is about 4.648 members, and 44.3% of households are involved in non-farm activities. Regarding landholdings, the mean rice land area is 1,042 m^2, while the total agricultural land averages 2,115 m^2, indicating substantial variability in land access, as reflected by large standard deviations. These statistics reveal a diverse sample with notable differences in economic, social, and demographic attributes.

Table 3 presents a balance test that compares unmatched and matched samples regarding membership in women's organizations, emphasizing essential household characteristics. In the unmatched sample, notable differences are observed between the treated and control groups regarding variables including the age of the household head, gender,

Table 1 Definition of variables used in the study

Variables	Definition	Expected sign	Previous research
Water security	1 = household has enough water for agricultural production; 0 = otherwise		
Membership of the women's association	1 = membership in women's association; 0 = otherwise	+	Armah et al., [30]; Okeniyi & Ajayi, [31]
Membership of the Farmer Association	1 = membership in Farmers' association; 0 = otherwise	+	Huong et al., [32]; Rahut et al., [33]
Membership of the Elder Association	1 = membership in Elder association; 0 = otherwise	+	Armah et al., [30]; Okeniyi & Ajayi, [31]
Membership in a Cooperative organization	1 = membership in Farmers' association; 0 = otherwise	+	Garrone et al., [34]; Liu et al., [35]
Diversity of the Organization's Membership	The number of organizations joined by the household head (from 1 to 4)	+	Schewe et al., [36]
Age of household head	Years	+	Armah et al., [30]; Rahut et al., [33]
Gender of the household Head	1 = Male; 0 = Female	+	Armah et al., [30]; Rahut et al., [33]
The educational level of the Household Head	Schooling completed years	+	Armah et al., [30]; Rahut et al., [33]
Access to Credit	1 = if household usage credit; 0 = otherwise	+	Armah et al., [30]; Rahut et al., [33]
Rich Household	1 = if the household belongs to the list of rich households; 0 = otherwise	+	Armah et al., [30]; Rahut et al. [33]
Health Risk	1 = if the household head has a serious disease in one year; 0 = otherwise	-	Huong et al., [32]; Rahut et al. [33]
Saving	1 = if the household has savings in the bank; 0 = otherwise	+	Jägermeyr et al., [37]; Liu et al., [35]
Total Area of Rice Land	The total rice land cultivation area in one year	-	Rahut et al., [33]
Total Area of Agricultural Land	The total agricultural land cultivation area in one year	-	Rahut et al., [33]
Number of family members	Total membership in a household (person)	+	Armah et al., [30]; Rahut et al., [33]
Non-Farm	1 = household has income from non-farm; 0 = otherwise	+	Fabusoro et al., [38]

access to credit, health risk, savings, and land holding areas for both rice and agricultural land. Following matching, the disparities for the majority of variables decrease, as indicated by increased p-values. Nonetheless, certain disparities persist, including the total area of rice production, the agricultural land, and the educational level of the household head. The results demonstrate that matching enhances balance among groups for the majority of characteristics, although complete alignment is not attained for all variables.

The balance tests (Table 4) for unmatched and matched samples compared to membership in farmers' organizations indicate significant differences across variables in the unmatched sample, which are considerably diminished following the matching process. In the unmatched sample, variables such as the gender of the household head, education level, access to credit, health risk, total area of rice and agricultural land, number of family members, and non-farm activities demonstrate statistically significant differences. Post-matching, the differences significantly decrease, with the majority of p-values surpassing 0.05, suggesting enhanced balance. Variables including the age and gender of the household head, access to credit, and non-farm activities demonstrate a strong balance following matching, whereas rich household, savings and health risk exhibit some

Table 2 Descriptive statistics of the Samples.
Source: Author's elaboration

Variable		Mean	Std. dev
Dependent Variables			
Water security	(1: Yes; 0: Others)	0.563	0.496
Interested Variables			
Membership of the women's association	(1: Yes; 0: Others)	0.497	0.500
Membership of the Farmer Association	(1: Yes; 0: Others)	0.338	0.474
Membership of the Elder Association	(1: Yes; 0: Others)	0.127	0.333
Membership in a Cooperative organization	(1: Yes; 0: Others)	0.142	0.349
Control Variables			
Age of household head	(Years)	49.048	10.605
Gender of the household Head	(1: Male; 0: Female)	0.528	0.500
The educational level of the Household Head	(Years)	3.130	1.038
Access to Credit	(1: Yes; 0: Others)	0.557	0.497
Rich Household	(1: Yes; 0: Others)	0.183	0.387
Health Risk	(1: Yes; 0: Others)	0.292	0.455
Saving	(1: Yes; 0: Others)	0.158	0.365
Total Area of Rice Land	(m^2)	1042.167	2810.168
Total Area of Agricultural Land	(m^2)	2115.715	4300.771
Number of family members	Number	4.648	1.327
Non-Farm	(1: Yes; 0: Others)	0.443	0.497

Table 3 Balance tests comparing unmatched and matched samples for Membership in Women's Organizations.
Source: Author's elaboration

Variables	Unmatched			Matched		
	Treat	Control	*P*-Value	Treat	Control	*P*-Value
Age of household head	47.789	20.291	0.004	47.789	48.762	0.196
Gender of the household Head	0.396	0.659	0.000	0.396	0.426	0.455
The educational level of the Household Head	3.087	3.172	0.317	3.087	2.906	0.022
Access to Credit	0.651	0.464	0.000	0.651	0.621	0.444
Rich Household	0.188	0.179	0.773	0.188	0.211	0.474
Health Risk	0.221	0.361	0.000	0.221	0.101	0.000
Saving	0.101	0.215	0.000	0.101	0.067	0.140
Total Area of Rice Land	591.63	1483.8	0.000	594.63	865.77	0.030
Total Area of Agricultural Land	1098.1	3119.8	0.000	1098.1	1591.5	0.013
Number of family members	4.601	4.695	0.383	4.601	4.523	0.451
Non-Farm	0.483	0.404	0.051	0.483	0.456	0.512

residual imbalance. The results suggest that matching effectively reduces differences between treatment and control groups, improving the comparability of the samples.

Table 5 presents balance tests comparing unmatched and matched samples for membership in elder's organizations. In the unmatched sample, significant differences exist between treated (members) and control (non-members) groups for age of household head, educational level, and non-farm activities, indicating imbalances in these covariates. After propensity score matching (PSM), these differences are substantially reduced, confirming improved balance. Most other covariates, including gender, rich household status, health risk, and total area of rice land, show no significant differences in either sample, indicating they were balanced initially and remained so post-matching. However, access to credit becomes significantly imbalanced after matching, suggesting a potential confounding factor. Overall, PSM effectively reduced most imbalances,

Table 4 Balance tests comparing unmatched and matched samples for Membership in farmers' organizations.
Source: Author's elaboration

Variables	Unmatched			Matched		
	Treat	Control	*P*-value	Treat	Control	*P*-value
Age of household head	49.601	48.766	0.362	49.601	49.488	0.905
Gender of the household Head	0.611	0.486	0.004	0.611	0.626	0.760
The educational level of the Household Head	2.961	3.217	0.004	2.961	2.951	0.916
Access to Credit	0.626	0.521	0.015	0.626	0.645	0.681
Rich Household	0.192	0.179	0.691	0.192	0.355	0.000
Health Risk	0.202	0.338	0.001	0.202	0.123	0.031
Saving	0.148	0.164	0.613	0.148	0.064	0.006
Total Area of Rice Land	1575.6	769.42	0.001	1575.6	1591.9	0.962
Total Area of Agricultural Land	3752.5	1278.9	0.000	3752.5	3392.4	0.502
Number of family members	4.852	4.544	0.007	4.852	4.690	0.261
Non-Farm	0.320	0.506	0.000	0.320	0.360	0.403

Table 5 Balance tests comparing unmatched and matched samples for Membership in Elder's Organizations.
Source: Author's elaboration

Variables	Unmatched			Matched		
	Treat	Control	*P*-value	Treat	Control	*P*-value
Age of household head	58.197	47.721	0.000	58.197	57.237	0.574
Gender of the household Head	0.526	0.529	0.970	0.526	0.513	0.872
The educational level of the Household Head	2.553	3.213	0.000	2.553	2.500	0.737
Access to Credit	0.487	0.567	0.190	0.487	0.303	0.020
Rich Household	0.197	0.181	0.736	0.197	0.211	0.842
Health Risk	0.316	0.288	0.621	0.316	0.250	0.371
Saving	0.224	0.149	0.095	0.224	0.145	0.212
Total Area of Rice Land	898.68	1063.0	0.634	898.680	670.8	0.287
Total Area of Agricultural Land	2913.20	2000.0	0.084	2913.200	3015.9	0.908
Number of family members	4.842	4.620	0.173	4.842	4.474	0.079
Non-Farm	0.329	0.460	0.032	0.329	0.368	0.612

enhancing the comparability of treated and control groups, though the imbalance in access to credit warrants further consideration.

Table 6 presents balance tests comparing unmatched and matched samples for households participating in cooperative organizations. In the unmatched sample, significant differences exist between treated (members) and control (non-members) groups for age of household head, educational level, gender, savings, total area of rice land, total area of agricultural land, number of family members, and non-farm activities, indicating systematic imbalances. After propensity score matching (PSM), most variables achieve balance, confirming improved comparability. Other variables, such as access to credit, rich household status, and health risk, show no significant differences in either sample, indicating they were balanced initially and remained so post-matching. However, gender remains significantly imbalanced after matching, suggesting a potential confounding factor. Overall, PSM substantially reduces most imbalances, enhancing the comparability of treated and control groups, though the imbalance in gender warrants further consideration.

Propensity Score Matching (PSM) employs propensity scores to balance pre-treatment characteristics between treatment (membership) and control (non-membership) groups.

Table 6 Balance tests comparing unmatched and matched samples for Membership in cooperative Organizations.
Source: Author's elaboration

Variables	Unmatched			Matched		
	Treat	Control	*P*-value	Treat	Control	*P*-value
Age of household head	56.400	47.835	0.000	56.400	57.494	0.460
Gender of the household Head	0.647	0.509	0.018	0.647	0.788	0.041
The educational level of the Household Head	2.647	3.210	0.000	2.647	2.612	0.801
Access to Credit	0.518	0.563	0.435	0.518	0.541	0.760
Rich Household	0.153	0.188	0.435	0.153	0.164	0.835
Health Risk	0.318	0.287	0.570	0.318	0.247	0.309
Saving	0.306	0.134	0.000	0.306	0.247	0.394
Total Area of Rice Land	1635.3	944.3	0.036	1635.300	1870.6	0.663
Total Area of Agricultural Land	3823.6	1833.8	0.000	3823.600	3375.5	0.577
Number of family members	5.541	4.501	0.000	5.541	5.235	0.266
Non-Farm	0.176	0.212	0.000	0.176	0.212	0.563

The process begins by evaluating the overlap in propensity score distributions between the two groups. Post-matching, these distributions are visualized in Fig. 3 (women's association), Fig. 4 (farmers' association), Fig. 5 (elders' association), and Fig. 6 (cooperative association). None of the graphs shows significant probability accumulation at 0 or 1. Moreover, the estimated density curves are highly similar, with their primary masses closely aligned, indicating no violation of the overlap assumption. The study displays propensity score distributions before and after matching in Figs. 3–6. Before matching, the distributions for membership (blue line) and non-membership (black line) differ noticeably. After applying PSM, the propensity score distributions for both groups become closely aligned, demonstrating effective balancing.

The study identifies factors influencing participation in various organizations, including those for women, farmers, elders, and cooperatives, concerning the characteristics of household heads (Table 7). The logit estimation results indicate that older farmers are more likely to join elder and cooperative organizations than younger farmers, with coefficients of 0.106 and 0.653, respectively. The education level of the household head did not positively influence rice farmers' participation in social organizations, as indicated by coefficients of -0.198, -0.265, -0.627, and -0.343 for women, farmers, elders, and cooperative organizations, respectively. The coefficients for rice farms with access to credit and social networks, including women's and farmer organizations, are 0.911 and 0.747, respectively, indicating a positive relationship. Additionally, households facing health risks are less likely to participate in various social groups, including women, farmers, and cooperative organizations, with coefficients of -1.050, -1.276, and -3.017, respectively.

Furthermore, households lacking savings exhibit a participation coefficient of −0.598 in women's organizations, whereas households with savings facilitate the membership of rice farmers in cooperative organizations. The number of family members positively influences the participation of women, farmers, and cooperative organizations, with coefficients of 0.143, 0.151, and 0.480, respectively. Large families are more likely to motivate households to engage with more social networks than smaller households. Finally, households engaged in non-farm activities significantly decrease the likelihood of participating in farmer and cooperative organizations by 1%.

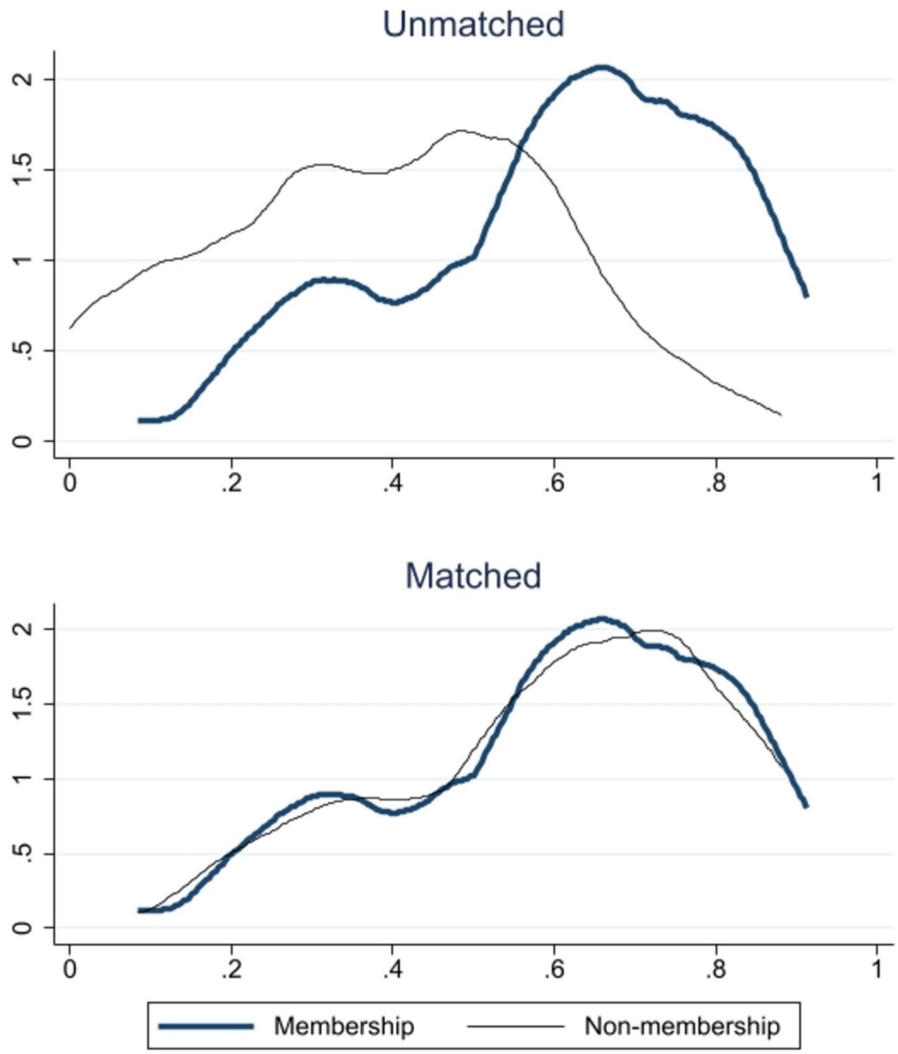

Fig. 3 Distribution of Propensity Scores before and after matching for Membership in Women's Organization. Source: Author's elaboration

Table 8 presents the effect of each social network, such as membership in each organization, on water security under the use or nonuse of PSM in Central Vietnam. Before PSM, the average effect of membership in women's organizations was not significant. In addition, households with membership in each organization, such as farmers, elders, and cooperative organizations, tend to ensure water security for rice production. However, after using PSM, results show that membership in women's organizations can reduce water security or increase the conflict of using water in rice production, with a coefficient of −0.332. In contrast, membership in the cooperative organization can improve rice production's water security, with a coefficient of 0.318 after using PSM. This study found no significant correlation between membership in the farmer or elder organization and water security after using PSM.

Table 9 presents the impact of social network membership on water security in rice production in Central Vietnam. The significant endogeneity test results confirm that social network participation is endogenous, necessitating the use of instrumental variable (IV) methods over ordinary least squares (OLS) or propensity score matching

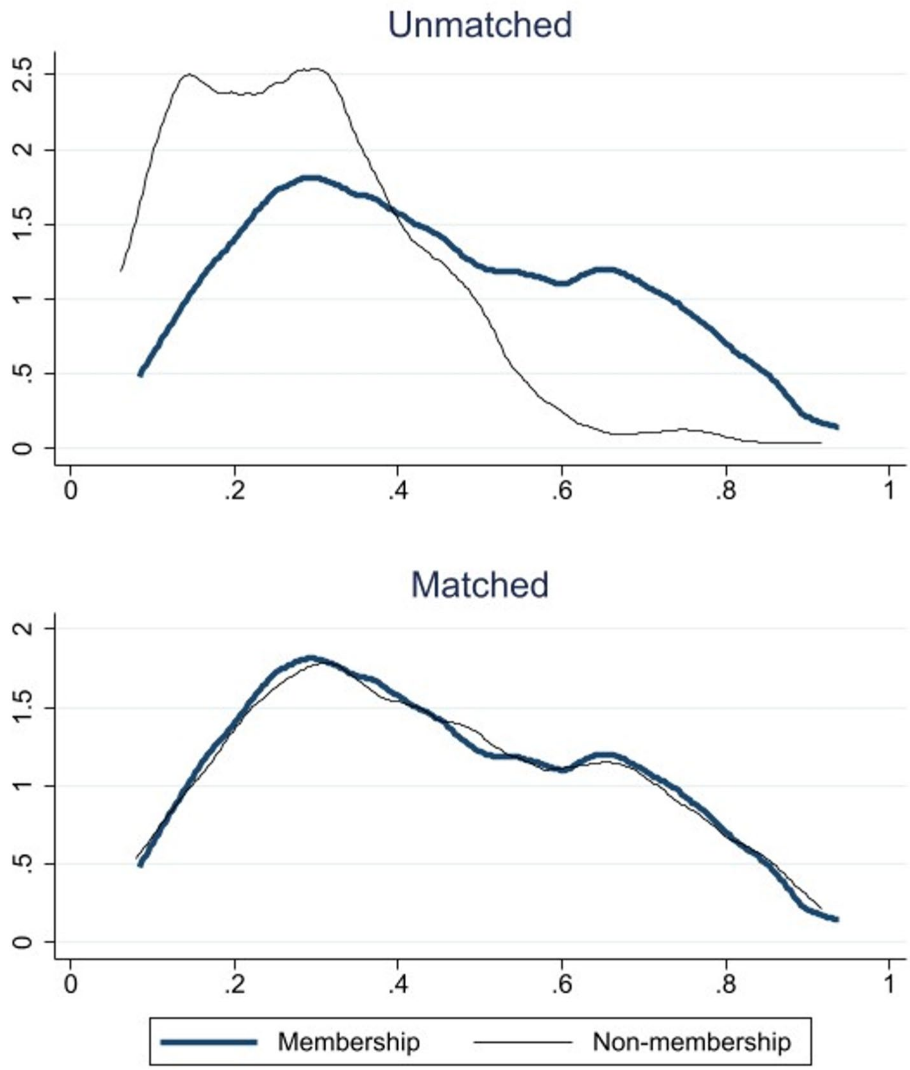

Fig. 4 Distribution of Propensity Scores before and after matching for Membership in Farmer Organization. Source: Author's elaboration

(PSM). Failure to account for endogeneity would yield biased estimates, as evidenced by the divergence between PSM and IV results, particularly for membership diversity. External instrumental variables, such as the distance from the household to the community center, are employed to identify the causal effect of social network membership on water security.

The IV estimation reveals that membership in women's organizations reduces water security in rice production, with a coefficient of −0.985, consistent with PSM findings. Conversely, membership in cooperative organizations enhances water security, with a coefficient of 2.790, aligning closely with PSM results. Notably, greater diversity in organizational membership is associated with reduced water security, with an IV-estimated coefficient of −1.345. Additionally, IV estimations identify several factors influencing water security, including the household head's age and education level, health risks, savings, family size, and participation in non-farm activities.

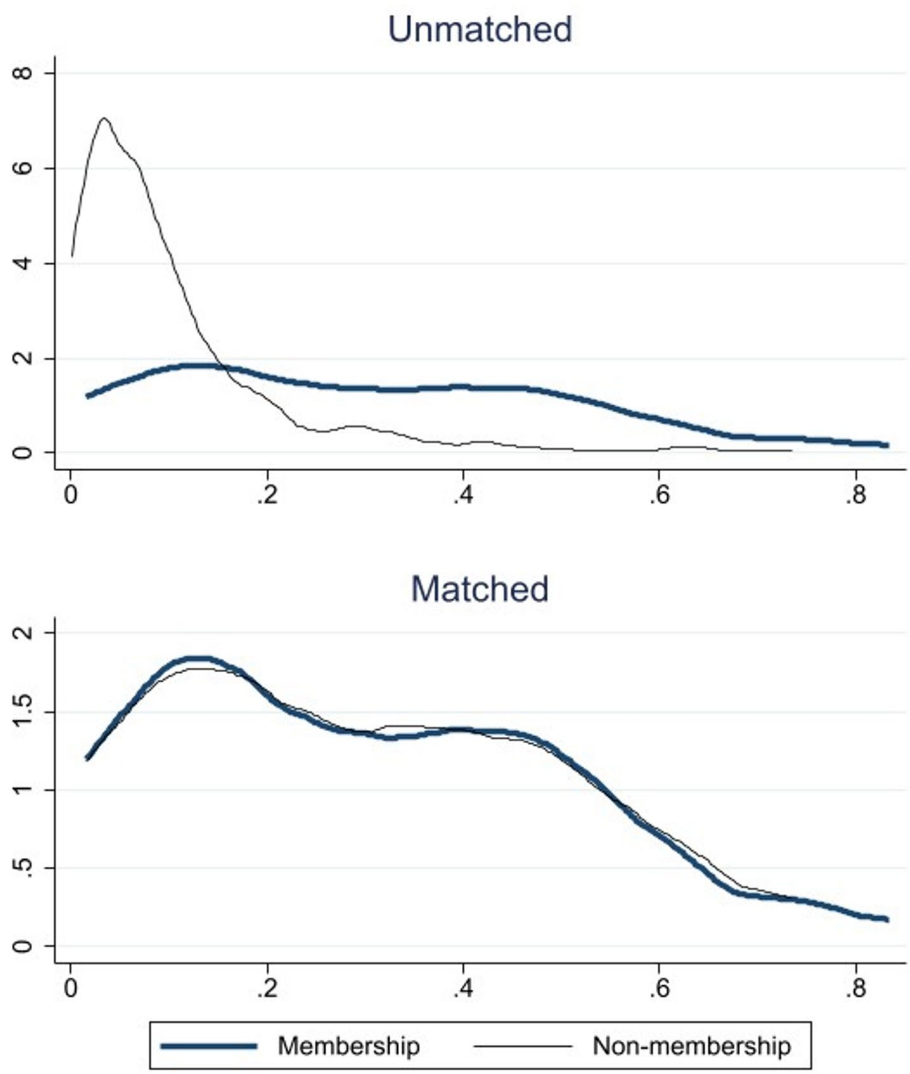

Fig. 5 Distribution of Propensity Scores before and after matching for Membership in Elder Organization. Source: Author's elaboration

5 Discussion

This study provides critical insights into the complex relationship between social network participation and water security in rice production in Central Vietnam. The findings, detailed in Tables 8 and 9, reveal divergent impacts of organizational memberships and the diversity of involvement, underscoring the nuanced role of social networks in agricultural water management.

Propensity score matching analysis indicates a counterintuitive finding that membership in women's organizations is associated with a reduced probability of water security in rice production (Table 8). This result challenges the assumption that collective action inherently enhances resource management and requires careful interpretation in the context of gender dynamics in Central Vietnam. Women's roles in agricultural water management are often informal and lack formal recognition, leading to inefficiencies and suboptimal practices [39]. The absence of institutional support for women's initiatives may hinder their ability to improve water security effectively. Moreover, women

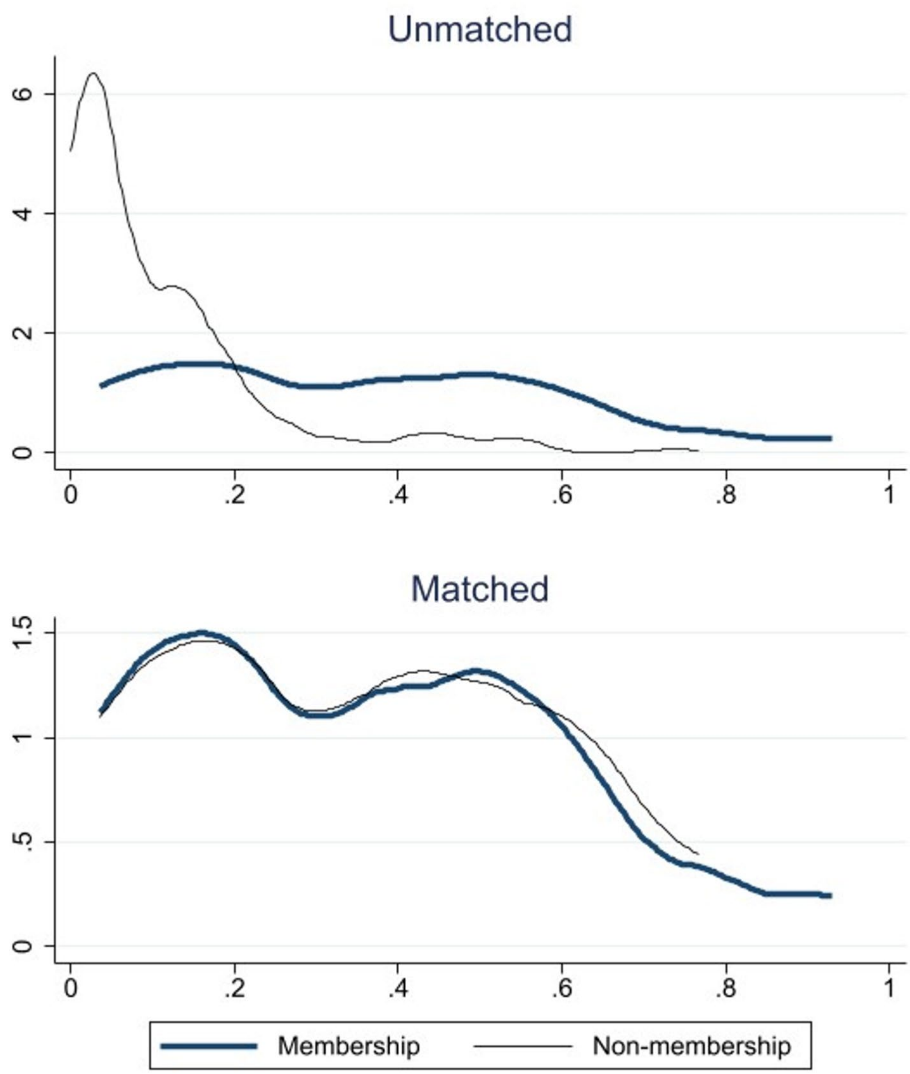

Fig. 6 Distribution of Propensity scores before and after matching for Membership in Cooperative Organization. Source: Author's elaboration

in agricultural communities disproportionately bear the impacts of environmental degradation and climate change, resulting in increased workloads for water collection and farming tasks [40]. This burden can perpetuate a cycle of resource depletion, where heightened responsibilities do not translate into improved water security. Systemic barriers, such as limited empowerment, restricted access to resources, or inadequate training within these organizations, may exacerbate water management challenges, contributing to the observed negative association. In rural Central Vietnam, women contribute to agricultural productivity and household resource management but are often disregarded. They often handle regular household duties and farming operations like transplanting, weeding, and, most significantly, water collection for domestic and agricultural use. Caregiving and labor need a disproportionate amount of time, decision-making power, and ability to participate in formal irrigation planning or community water governance. Women are involved in water-related decision-making, but gender conventions, a lack of technical water management training, and a lack of local

Table 7 Factors linked to participating in various organizations

Variables	Women Organization	Farmer Organization	Elder Organization	Cooperative Organization
	Coefficient	**Coefficient**	**Coefficient**	**Coefficient**
Age of household head	−0.016	−0.007	0.106***	0.063***
	(0.010)	(0.010)	(0.016)	(0.015)
Gender of the household Head	−1.172***	0.455**	−0.093	0.430
	(0.193)	(0.195)	(0.278)	(0.287)
The educational level of the Household Head	−0.198**	−0.265**	−0.627***	−0.343**
	(0.096)	(0.104)	(0.169)	(0.166)
Access to Credit	0.911***	0.747***	0.220	−0.051
	(0.208)	(0.212)	(0.296)	(0.293)
Rich Household	−0.024	0.093	0.580	−0.501
	(0.273)	(0.270)	(0.392)	(0.424)
Health Risk	−1.050***	−1.276***	−0.676	−3.017***
	(0.274)	(0.353)	(0.488)	(1.057)
Saving	−0.598*	0.509	0.637	3.363***
	(0.362)	(0.430)	(0.568)	(1.084)
Total Area of Rice Land	−0.000	−0.000	−0.000*	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Total Area of Agricultural Land	−0.000***	0.000***	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Number of family members	0.143*	0.151*	−0.095	0.480***
	(0.079)	(0.078)	(0.112)	(0.103)
Non–Farm	−0.269	−0.604***	0.321	−1.058***
	(0.210)	(0.218)	(0.319)	(0.348)
Constant	1.727**	−0.617	−5.516***	−6.238***
	(0.691)	(0.722)	(1.113)	(1.095)
Observations	600	600	600	600

Standard errors in parentheses.*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 8 The effect of membership in various organizations on water security by PSM. *Source*: Author's elaboration

Variables	Membership in women's organization	Membership in the farmers' organization	Membership in the elders' organization	Membership in Cooperative Organization
	Coefficient	**Coefficient**	**Coefficient**	**Coefficient**
Membership in Various Organizations (1: Yes; 0: Otherwise)- Unmatched	−0.355	0.095***	0.428***	0.467***
	(0.043)	(0.033)	(0.027)	(0.024)
Membership in Various Organizations (1: Yes; 0: Otherwise)- Matched	−0.332***	0.094	0.145	0.318***
	(0.069)	(0.054)	(0.060)	(0.072)
Observations	600	600	600	600

Each coefficient is a separate estimation by using the PSM method.

Standard errors in parentheses;*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

organization leadership limit their engagement [41, 42]. Women's groups often prioritize social welfare or livelihood support over water management [41]. In times of water scarcity, these groups may lack the structural and technical capacity to influence water distribution decisions or infrastructure upkeep, resulting in inefficiency and even clashes. Without gender-sensitive training or agricultural extension services, women may struggle to adopt water-saving technologies or change irrigation schedules [43, 44]. These

Table 9 The effect of membership in various organizations on water security by instrumental variables.
Source: Author's elaboration

Variables	Coef	Coef	Coef	Coef	Coef
Membership in Women's Organization	−0.985***	–	–	–	–
	(0.219)	–	–	–	–
Membership in the Farmers' Organization	–	−3.875	–	–	–
	–	(2.959)	–	–	–
Membership in the Elders' Organization	–	–	5.834	–	–
	–	–	(4.450)	–	–
Membership in Cooperative Organization	–	–	–	2.790***	–
	–	–	–	(1.065)	–
Diversity of the Organization's Membership	–	–	–	–	−1.345**
	–	–	–	–	(0.633)
Age of household head	0.010***	0.009	−0.045	−0.004	0.029***
	(0.002)	(0.008)	(0.044)	(0.007)	(0.009)
Gender of the household Head	−0.190***	0.389	0.043	−0.066	−0.095
	(0.067)	(0.306)	(0.149)	(0.095)	(0.112)
The educational level of the Household Head	−0.115***	−0.256*	0.222	−0.007	−0.295***
	(0.023)	(0.154)	(0.243)	(0.053)	(0.111)
Access to Credit	−0.005	0.402	−0.315*	−0.276***	0.355
	(0.063)	(0.480)	(0.188)	(0.093)	(0.275)
Rich Household	0.031	0.074	−0.246	0.227*	0.045
	(0.061)	(0.212)	(0.298)	(0.134)	(0.130)
Health Risk	−0.321***	−0.978	0.060	0.274	−0.905**
	(0.081)	(0.701)	(0.258)	(0.211)	(0.400)
Saving	0.011	0.404	−0.242	−0.483	0.426*
	(0.084)	(0.374)	(0.375)	(0.318)	(0.238)
Total Area of Rice Land	0.000	−0.000	0.000	0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Total Area of Agricultural Land	−0.000**	0.000	−0.000	−0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Number of family members	0.033*	0.134	0.113	−0.127*	0.130*
	(0.018)	(0.111)	(0.098)	(0.068)	(0.067)
Non-Farm	−0.082*	−0.519	−0.111	0.217	−0.367**
	(0.048)	(0.393)	(0.168)	(0.142)	(0.179)
Constant	1.040***	1.400	1.071	1.096***	1.133**
	(0.239)	(1.039)	(0.836)	(0.422)	(0.538)
Endogeneity test	16.790***	30.415***	27.546***	24.525***	30.272***
Cragg-Donald Wald F statistic	28.154	1.855	1.629	6.940	5.435
Observations	600	600	600	600	600

Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

contextual factors explain the negative correlation between women's group membership and rice farming water security.

In contrast, propensity score matching results demonstrate that participation in cooperative organizations significantly enhances water security in rice production (Table 8). This finding aligns with existing research highlighting the benefits of cooperative models in natural resource management [45–48]. The positive effect of cooperatives stems from several factors. First, cooperatives engage community members in participatory decision-making, fostering trust, accountability, and a sense of ownership, essential for sustainable water resource management [49]. This approach ensures that water management policies are tailored to local needs, promoting equitable and efficient water allocation. Second, cooperatives facilitate community-based agreements for water management, empowering local stakeholders to collectively manage shared resources [50]. These initiatives improve access to water quality and quantity, highlighting the value of cooperative governance. Additionally, cooperatives provide platforms for knowledge sharing, resource pooling, and investment in water infrastructure, all of which enhance water security outcomes.

While the mechanisms through which cooperatives and women's organizations significantly influence water security, the effects of farmer and elder associations are not significant. These two types of organizations did not show statistically significant effects under PSM or IV estimation. This could reflect their limited role in water governance. Farmer associations may lack formal authority or resources to coordinate collective water management effectively, functioning primarily as informational or advocacy platforms [51]. Similarly, elder organizations may serve social or ceremonial functions rather than resource governance roles, thus explaining their minimal impact [52].

Instrumental variable (IV) estimation reveals that greater diversity in organizational affiliations is associated with water security in rice production (Table 9). This finding suggests that participation in multiple social networks does not inherently benefit water security and may even be detrimental. This negative correlation likely arises due to organizational heterogeneity and coordination challenges [53]. Diverse organizations often pursue conflicting objectives. Additionally, participation in multiple networks can strain individuals' time and resources, diluting their contributions to effective water resource management [54]. These findings highlight the need for coordinated efforts among organizations to align goals and optimize resource use. Further research should explore how to mitigate the potential drawbacks of diverse memberships while leveraging their collective strengths.

Although propensity score matching (PSM) and instrumental variable (IV) methods generally align in the direction of effects on water security in rice production in Central Vietnam, significant differences in estimate magnitudes highlight the importance of addressing endogeneity. For instance, women's organization membership has a smaller negative effect on water security under PSM compared to a stronger negative impact under IV, while cooperative organization membership shows a larger positive effect under IV than PSM. These disparities suggest that PSM may not fully account for unobserved confounders, such as internal organizational dynamics, implementation effectiveness, or selection biases tied to latent community factors, whereas IV methods, leveraging exogenous variation like distance to the community center, yield more robust causal estimates. The consistent negative effect of women's organization membership and positive effect of cooperative membership across both methods, combined with IV's stronger estimates, underscore the value of using multiple estimation strategies to triangulate causal relationships and enhance the reliability of findings.

6 Conclusion

This study provides novel and context-specific insights into the differential impacts of social network participation on water security in rice production in Central Vietnam. While previous research has broadly examined the role of social capital in agriculture, our findings distinctly highlight that not all social network memberships are equally beneficial, and some, like diverse organizational involvement or membership in women's organizations in this specific context, can even pose challenges to water security. Specifically, by employing robust econometric methods such as propensity score matching and instrumental variables estimation, this research empirically demonstrates that cooperative organization membership significantly enhances water security, whereas membership in women's organizations and, importantly, the sheer diversity of organizational memberships, negatively affect it. This nuanced understanding contributes significantly to the literature on agricultural water management, social capital, and rural development in Southeast Asia, offering specific implications for policy and practice beyond general assumptions.

Using Propensity score matching (PSM) to reduce the selection bias, the result of this study indicates that membership in women's organizations reduces water security in rice production. However, membership in a cooperative organization improves the water security in rice production after using PSM. The study also applies the instrumental variable method to check for robustness of the effect of membership in social networks on water security. More interestingly, the study indicates that the diversity of social networks reduces water security under the IV estimation. To ensure water security in rice production, the government should promote cooperative organizations, which have been shown to improve water security, while addressing potential challenges posed by women's organizations and diverse social networks. This can be achieved through investing in training for leaders and members on effective governance, conflict resolution for water allocation, financial management, and democratic decision-making, including data collection for monitoring. To foster efficient water management, establish platforms for inter-cooperative learning and best practice sharing, such as forums, visits, and online portals.

Our research has specific limitations. Detailed membership information in social networks was not available until 2024, and accessible data collection and longitudinal or panel data were absent. Thus, we could not analyze the impact of social network participation on water security over time. Using panel data to create water security plans for rice farms would reduce bias because it takes into account household variables that can't be seen and stay the same over time. This indicates that additional study is necessary to resolve this issue, considering the accessibility of panel data. Additionally, the convenience sampling method may introduce selection bias, compromising the representativeness of the sample for Central Vietnam. To enhance the study's validity, a larger, more diverse sample size should be employed, ideally managed by government authorities to ensure robust and generalizable findings.

Appendix 1

See Table 10.

Table 10 First step of the instrumental variables method. *Source*: Author's elaboration

Variables	**Membership in a women's organization**	**Membership in the Farmer organization**	**Membership in the Elder organization**	**Membership in a Cooperative organization**	**Diversity in social organization**
	Coefficient	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**
Age of household head	0.00	0.00	0.01***	0.01***	0.01***
Gender of the household Head	−0.23***	0.09**	0.00	0.04	−0.10
The educational level of the Household Head	−0.02	−0.04**	−0.05***	−0.03**	−0.15***
Access to Credit	0.14***	0.14***	0.03	0.06**	0.37***
Rich Household	−0.02	0.01	0.05	−0.04	0.00
Health Risk	−0.22***	−0.23***	−0.03	−0.12***	−0.60***
Saving	−0.07	0.08	0.06	0.19***	0.26**
Total Area of Rice Land	0.00	0.00	0.00*	0.00	0.00**
Total Area of Agricultural Land	0.00***	0.00***	0.00	0.00	0.00*
Number of family members	0.04***	0.04**	−0.02*	0.05***	0.10***
Non-Farm	−0.05	−0.12***	0.01	−0.09***	−0.25***
Distance from home to the community center	0.05***	0.01	−0.01	−0.02***	0.03**
Constant	0.49***	0.22	−0.09	−0.19*	0.43
Underidentification test	27.461	1.891	1.661	7.01***	5.51**
Cragg-Donald Wald F statistic	27.154	1.855	1.629	6.94	5.43
Endogeneity test	16.790***	30.415***	27.546***	24.53***	30.27***

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Appendix 2

Questionnaire: Social Networks and Water Security in Rice Production.

I. General Information

1. Name of respondent: ______________________________
2. Date of interview: ________________________________
3. Commune/Ward: ________________________________
4. District: ______________________________________
5. Province: _____________________________________

II. Household Demographics and Characteristics

6. Age of household head (in years): ____________

7. Gender of household head

☐ Male (1)

☐ Female (0)

8. What is the highest grade/year of school completed by the household head?

_________ years

9. How many people currently live in your household?

_________ persons

6,010. Does your household currently have access to credit (formal or informal)?

☐ Yes (1)

☐ No (0)

11. Is your household listed as a 'rich' household by the local authorities?

☐ Yes (1)

☐ No (0)

12. Does any member of your household have savings in a bank or credit institution?

☐ Yes (1)

☐ No (0)

13. Does your household have income from non-farm activities (e.g., trade, services, labor)?

☐ Yes (1)

☐ No (0)

14. Has the household head suffered from any serious disease within the past 12 months?

☐ Yes (1)

☐ No (0)

IV. Land Use

15. What is the total area of rice land cultivated by your household this year?

__________ m²

16. What is the total area of all agricultural land cultivated by your household this year (including rice land)?

__________ m²

V. Social Network Participation

17. Are you currently a member of a women's association?

☐ Yes (1)

☐ No (0)

18. Are you currently a member of a farmers' association?

☐ Yes (1)

☐ No (0)

19. Are you currently a member of an elder association?

☐ Yes (1)

☐ No (0)

20. Are you currently a member of a cooperative organization related to agriculture?

☐ Yes (1)

☐ No (0)

VI. Water Security

22. In the last cropping season, did your household have sufficient water for rice production?

☐ Yes (1)

☐ No (0)

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Author contributions
Author Contributions: P.N.T.: Conceptualization, Data collection, Software, Writing—review and editing. M.N.H.D: Writing—original draft, Methodology. A.L.T.: Supervise, write, review, and edit. H.N.T.T.: Conceptualization, Writing—original draft. D.N.C: Writing—original draft, Methodology. K.N.D: write, review, and edit.

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Data availability
The Data is available upon the request.

Declarations

Ethics approval and consent to participate
Not applicable.

Competing interests
The authors declare no competing interests.

Consent to publish
All authors agree to publish this research.

Clinical trial number
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