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Adoption of water-efficient irrigation systems in small-scale farms in the south of Bakhtegan Lake, Iran

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ABSTRACT

Efficient farm water resource management plays an important role in the development of rural areas, especially in dry and semi-dry regions like Iran. Modern irrigation systems can serve as a foundation for better farm water management. Therefore, the present study investigated the impact of socioeconomic factors on the adoption of modern irrigation systems among farmers in the southern regions of Bakhtegan Lake, Iran, using the Logit econometric method. Applying the random sampling method and Cochran's formula, the sample size was determined to include 350 farmers who were surveyed in the summer of 2022. The results of the empirical model indicated that the head of the household's education, access to communication infrastructure and information, off-farm income, saving ability, and livelihood diversity have a positive and significant effect on the adoption of modern irrigation systems. Conversely, the number of family workers has a significant negative impact on the adoption of modern irrigation systems. Additionally, the receipt of subsidies and the age of the head of the household do not significantly affect the adoption of these technologies.

Highlights

- Socioeconomic factors have a positive impact on the adoption of modern irrigation systems in the south of Bakhtegan Lake, Iran.
- Access to the communication infrastructure and information positively influences the adoption of modern irrigation systems.
- The number of family workers hinders the adoption of modern irrigation systems.

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1. Introduction

The imbalance between global water supply and demand has reached a critical point. Water scarcity, driven by increased demand and reduced availability from drought and climate change, is now one of the most urgent societal challenges (Mekonnen and Hoekstra, 2016; Scanlon et al., 2023). Water's importance as a resource has grown due to scarcity. It plays a crucial role in agriculture (D'Odorico et al., 2020), which uses 70–80% of global freshwater (Wu et al., 2022; Koch and Langat, 2018). Crop production accounts for 99% of direct use (Gerveni et al., 2020), and irrigated farms yield about 20% of agricultural output (Keating et al., 2014). In Iran's arid climate, over 90% of crops rely on irrigation (Soltani et al., 2020). Excessive agricultural withdrawals have made water the key barrier to development, demanding urgent supply- and demand-side solutions. Modern irrigation is essential for improving agricultural water use, which remains below 35% efficiency in Iran (Madani, 2014) compared to 70–90% in developed countries (FAO, 2016). Adopting modern systems can reduce water loss, improve farm-level efficiency, and enable greater coverage and yield with less groundwater use. This shift, however, poses challenges for farmers relying on pressurized technologies (Koech and Langat, 2018). Adoption patterns differ across farmers due to various socioeconomic conditions. Modern irrigation technologies reduce production risks and operational costs, encouraging investment in sustainable practices (Jahangirpour and Zibaei, 2022).

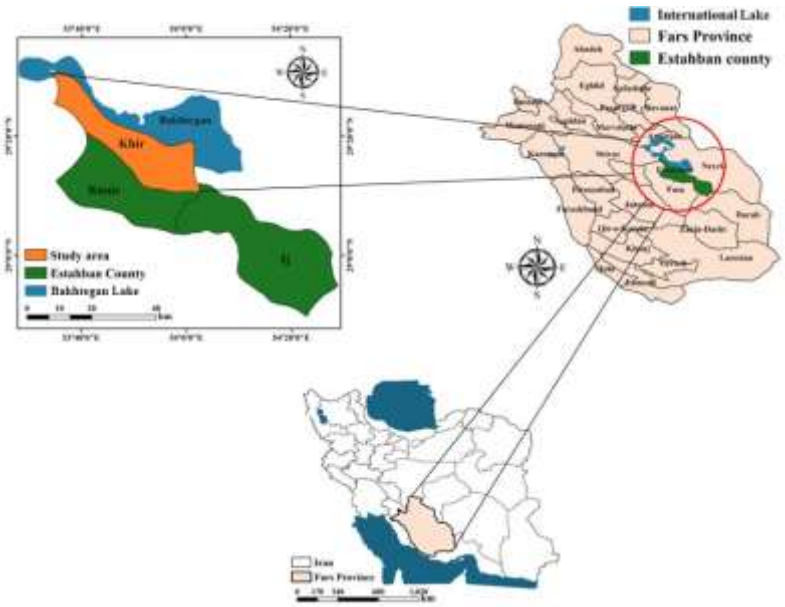
Prior studies across Asia and Africa have identified age, education, landholding size, farm income, off-farm employment, and access to credit as key factors influencing irrigation technology adoption (Chuchird et al., 2017; Yatribi, 2020; Weldesenbet, 2020). In Bangladesh, education and extension services promoted adoption, while credit access, farm size, and off-farm income had negative effects (Rana et al., 2021). Studies in India and South Africa pointed to income, land ownership, mass media exposure, and farming experience as key factors (Kumari et al., 2022; Mkuna and Wale, 2023). In Iran, formal education, farm size, and compatibility significantly influenced adoption across farmer groups (Yazdanpanah et al., 2023).

2. Materials and Methods

2.1 Study Area

The southern part of Bakhtegan Lake, located in Estahban County, Roniz District, and Khir Rural District, was selected as the study boundary. The prevalence of irrigated agriculture and reliance on farming for livelihoods made this area an ideal case study. Of the 45 villages in Khir District, only 12 remain inhabited due to drought impacts. Fig. 1 shows the geographical location of the study area.

Fig. 1 The study area in Fars province and Iran



Due to low adoption of modern irrigation systems in the area, this study examines key socioeconomic drivers affecting uptake among farmers south of Lake Bakhtegan. It is the first to assess the roles of subsidies and livelihood diversity in this context

2.2 Sampling method and data collection

Considering that the community under study comprises farmers in the study area and, according to statistics, the total number of farmers is 2800 persons, the sample size was calculated using the random sampling method according to Eq. 1 (Cochran, 1977).

$$n = \frac{N.t^2.p.q}{N.d^2+t^2.p.q} \quad (1)$$

where, n is the sample size, N is the population size, p is the probability of the attribute's presence, and q is the absence of the attribute equal to 0.5. Also, sampling accuracy depends on the factor d, and when we want the sampling to have the highest accuracy, the maximum value of d equal to 0.5 is used. The t value is also considered equivalent to 1.96 at the five% error level. The sample size obtained is equal to 338 people. However, due to the greater accuracy of the study and the generalization of the data with more confidence, a survey was conducted from 350 farmer households in the study area.

2.3 Econometrics approach

The normal distribution cannot be observed in models that use binary dependent variables; therefore, the logit model is used in such situations. This model has been applied in many economic studies due to its simplicity and breadth (Sinden and King, 1990). Hence, in the present study, the logit model as the most important discrete choice models, is utilized. The logit model is based on the assumption of unrelated options and the dependent variable has only two values, zero and one, representing the adoption and non-adoption of a new technology (Luce, 1959). The logit model used in this study is expressed as Eq. 2.

$$logit(p) = \ln\left(\frac{p_i}{1-p_i}\right) \quad (2)$$

If the farmers adopted and used modern irrigation systems (p=1); otherwise, it would be (p=0). In addition, the independent variables affecting adoption or non-adoption are given as x_{ik} in Eq. 3.

$$\varphi^{-1}(P_i) = \sum_{k=0}^{k=n} \beta_k x_{ik} \quad (3)$$

Eq. 4 shows the general form of the logit relationship used in this study.

$$\ln\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_1 Age + \beta_2 \text{Education} + \beta_3\ Labor\ + \beta_4 Access + \beta_5 Livelihood\ diversity + \beta_6 Income + \beta_7 Save + \beta_8 Subsidy \quad (4)$$

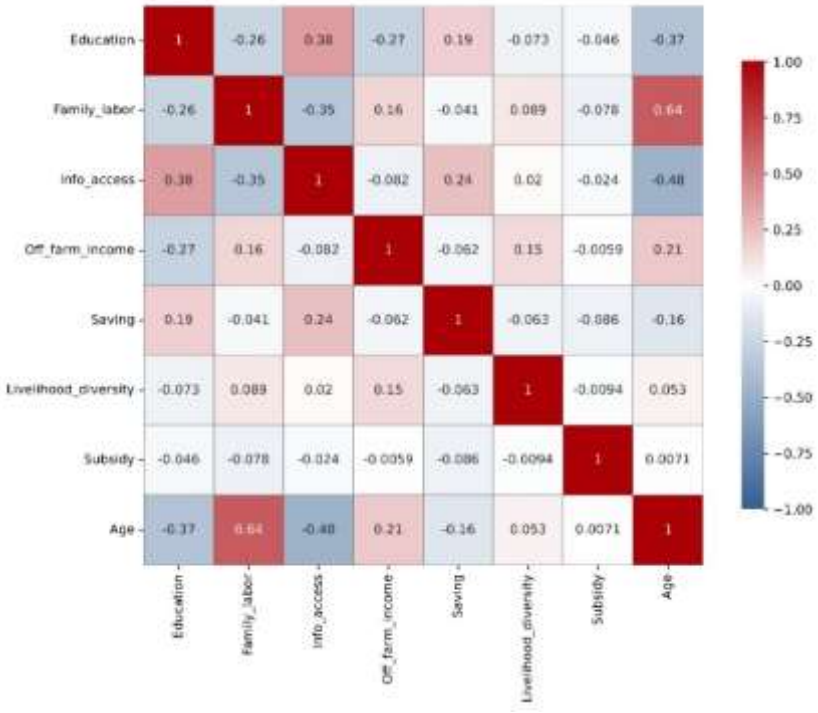
The model included variables such as age, education, family labor, access to information, off-farm income, savings, livelihood diversity, and receipt of government subsidies. Variable definitions followed standard demographic and economic indicators commonly used in adoption research.

Following model estimation, it is essential to assess the goodness of fit. For this purpose, two criteria Likelihood Ratio (LR) test and the Log-Likelihood value are examined. The LR test functions similarly to the F-statistic in ordinary least squares regression. If the null hypothesis of model insignificance is rejected, the fitted model is considered statistically significant and reliable. Moreover, a higher absolute value of the Log-Likelihood indicates a better model fit (Izadinia and Alinaghian, 2011).

3. Results and Discussion

A total of 350 farmers from 12 villages in Khir Rural District were surveyed to assess irrigation adoption patterns. These villages represent the active agricultural communities in the southern Bakhtegan basin. For brevity, several neighboring villages were grouped based on proximity and shared characteristics. Pairwise correlations indicated no serious multicollinearity among explanatory variables. To verify the independence of explanatory variables, a correlation heatmap was generated (Fig. 2). It indicates no severe multicollinearity problems among the predictors. The correlation heatmap displays pairwise Pearson correlation coefficients among the independent variables included in the logit regression model. The analysis is based on the actual dataset used in the study. Most correlation coefficients fall below 0.5, indicating a low risk of multicollinearity among the explanatory variables.

Fig. 2 Correlation Heatmap of Independent Variables



To understand the spatial variation in adoption behavior, Fig. 3 illustrates the proportions of adopter and non-adopter households across eight villages surrounding Bakhtegan Lake. The results reveal that non-adoption remains dominant in all villages, with adopters comprising a minority group. Adoption varied considerably across villages, with the highest rate in Damaneh (32.7%) and no adoption observed in Mobarakabad.

Fig. 3 Rate of Adoption of the modern irrigation system in the Study Area

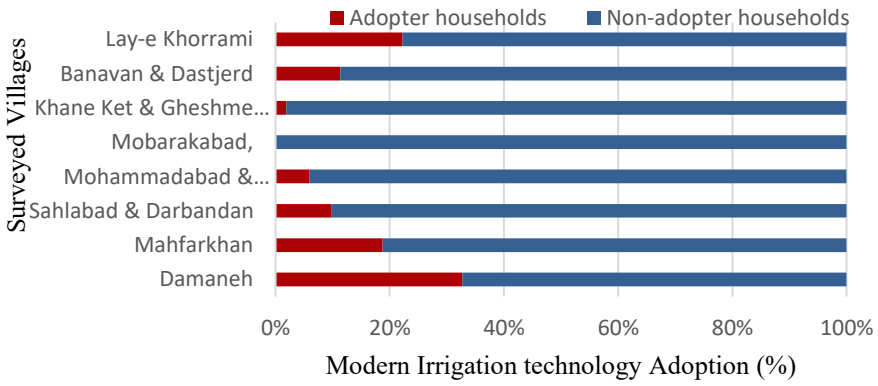


Table 1 presents the results of the logit regression model analyzing factors influencing household adoption of water-efficient irrigation systems. The logit results showed that the education level of the head of the household, access to infrastructure, off-farm income, savings ability, and livelihood diversity have a positive and significant effect on the adoption of modern irrigation systems among farmers in the south of Bakhtegan Lake. Meanwhile, the age of the household head and subsidies did not significantly affect the adoption of new irrigation technologies. Conversely, the number of family laborers has a negative and significant effect on the adoption of modern irrigation technologies. Additionally, the likelihood ratio (LR) test yielded a significant Chi-square statistic of 54.18, indicating strong evidence against the null hypothesis of model insignificance. Thus, the model is statistically significant and can be considered reliable. Furthermore, the Log-Likelihood value is -103.310. As a general rule, a higher absolute Log-Likelihood value reflects better model fit and greater explanatory power.

Table 1 Results of Logit model regression

Variable	The coefficient value	Standard Error
Age	- 0.006	0.020
Education	0.380 **	0.188
Family labor	- 0.540 ***	0.166
Information access	1.46 ***	0.521
Off-farm income	1.17 **	0.537
Saving	1.13 ***	0.403
Livelihood diversity	0.835 ***	0.274
Subsidy	- 0.202	0.574
Constant	-6.986***	1.4961
LR chi2 = 54.18***	Log likelihood = -103.310	Number of observations = 350

Note: ***, ** and * are significant level at the 1, 5 and 10%, respectively

Table 2 presents the marginal effects derived from the logit model, accompanied by their standard errors, to assess the influence of various household-level variables on the probability of adopting Water-Efficient Irrigation Systems. The marginal effects analysis showed that age had no significant impact on modern irrigation adoption, consistent with Afrakhteh et al. (2015). In contrast, higher education increased the adoption probability by 2%, as also supported by recent studies (Martínez-Arteaga et al., 2023; Kumari et al., 2022; Yazdanpanah et al., 2023). Educated farmers are often more informed about modern technologies and have better access to financial and administrative resources.

Table 2 The Marginal effects of the logit model

Variable	Marginal	Standard Error
Age	- 0.0001	0.0013
Education	0.025	0.012
Family labor	- 0.103	0.053
Information access	0.097	0.032
Off-farm income	0.077	0.034
Saving	0.075	0.027
Livelihood diversity	0.055	0.019
Subsidy	- 0.013	0.037

Family labor had a negative marginal effect: each additional family worker reduced the likelihood of adoption by 10%. This supports the idea that households with more internal labor tend to continue manual irrigation practices, as observed in Afrakhteh et al. (2015). Meanwhile, access to information technologies such as smartphones and the internet significantly boosted adoption likelihood by 9%, likely due to improved knowledge and access to support services (Kumari et al., 2022).

Off-farm income increased adoption by 7%, enabling farmers to finance irrigation upgrades, similar to findings by Yatribi (2020). Likewise, livelihood diversity (e.g., combining horticulture and livestock) improved adoption rates by 5%, contributing to income stability (Kumari et al., 2022). Savings also played a critical role, raising adoption probability by 7%, as greater financial security likely encouraged risk-taking and investment in new systems. Finally, government subsidy receipt showed no significant effect, suggesting access alone does not guarantee behavioral change.

4. Conclusion

This research examined the influence of socio-economic factors on the adoption of new irrigation systems by farmers in the Khir rural district of Estahban County. Geographically, this district is situated south of Bakhtegan Lake and contains 12 villages. In 2022, 350 farmers in the research area were face-to-face interviewed. The important results of present research can be summarized as follows:

1. According to the logit regression findings, the household head's education level positively and significantly influences farmers' adoption of new irrigation systems. Hence, it is suggested that relevant centers work on improving the literacy levels of illiterate and low-literacy farmers to inform them about the benefits of modern irrigation systems for farms.

2. Empirical results indicated that off-farm income and livelihood diversity have a significant positive effect on adoption. Therefore, it is suggested that farmers undertake side activities alongside horticulture and farming on their farms, such as multi-crop cultivation, animal husbandry, and beekeeping. This will reduce the risks associated with

agricultural activities, leading to increased income and, thus, an improved ability to save.

3. Additionally, econometric results showed the significant effect of access to social communication infrastructure. Hence, disseminating information through virtual channels, village councils, and other relevant means is recommended. Communication with promoters and facilitators can enhance this process.

Statements and Declarations
Data availability

The datasets analyzed during the current study are available from the corresponding author on reasonable request (tarazkar@shirazu.ac.ir).

Conflicts of interest

The author of this paper declared no conflict of interest regarding the authorship or publication of this paper.

Author contribution

M H. Tarazkar: Conceptualization, Supervision, Econometrics analysis, Editing and proofreading; F. Ardali: Data preprocessing, Econometrics analysis, Model implementation; F. Shokravi: Formal analysis, Writing - original draft.

AI Use Declaration

During the preparation of this manuscript, the authors used ZeroGPT for language translation. All content has been carefully reviewed and revised by the authors, who take full responsibility for the final version of the manuscript.

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