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SYNERGIZING SOCIOECONOMIC, TECHNOLOGICAL, AND ENVIRONMENTAL FACTORS INFLUENCING THE ADOPTION OF HIGH-EFFICIENCY IRRIGATION SYSTEMS (HEIS): INSIGHTS FROM HIGHLAND BALOCHISTAN, PAKISTAN

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ABSTRACT

Water plays a crucial role in sustaining human life and facilitating global economic development. Balochistan, the largest province of Pakistan, faces severe water scarcity primarily because of the unregulated extraction of groundwater aquifers. The scarcity of water resources can be effectively addressed by increasing Water Use Efficiency (WUE) achievable through the adoption of High-Efficienscy Irrigation Systems (HEIS). Despite substantial efforts by both public and private sectors, the adoption rate of efficient techniques remains notably low. Evaluating the factors influencing the adoption of high-efficiency irrigation methods and their resultant impact on water use efficiency is the need of time. In this study, an effort was made to study HEIS and its characteristics including the factors affecting the adoption decision, operation duration, and the economics of HEIS. The present study focused, on three main river basins using a multistage sampling technique in highland Balochistan. Three key basins namely Nari River Basin (NRB), Zhob River Basin (ZRB), and Pishin Lora Basin (PLB) Out of 18 basins in Balochistan were selected purposively. These basins are currently dealing with the issue of depleted groundwater table at a rate of more than 5-15 feet annually in the majority of their aquifers. A representative sample size of 300 farmers was chosen using a proportionate stratified sampling technique. Logistic regression was employed to analyze the data and the study findings revealed that the availability of off-farm income and higher education level were found to have highly significant and positive relationships with the likelihood of adoption. Farmers' age and the level of water scarcity were additional significant factors. Along with them, installation costs, maintenance expenses, and technological complexity were key barriers to HEIS adoption. To increase farmers' willingness to accept technology in highland Balochistan, organizations should undertake extension and educational training to increase knowledge and awareness of HEIS.

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INTRODUCTION

Flooding, a widely practices irrigation method used by farmers in Baluchistan, Pakistan, has an irrigation water efficiency of lower than 50% (IUCN, 2000; Latif et al., 2016). Such low irrigation efficiency is a key barrier to achieve potential output and leads to the injudicious use of groundwater resources (Bakhsh et al., 2020). Uneven fields and ineffective farm design lead to 25% of irrigation water wastage during application (Kaur et al., 2012). Excessive irrigation leaches down the dissolved nutrients from the crop root zone reduces soil fertility and deteriorates groundwater quality. Similarly, under-irrigation of elevated areas of the fields leads to salt accumulation while generating water stress and poor results from the applied fertilizer (Razzaq et al., 2018).

Balochistan is an arid, dry mountainous region (Qasim et al., 2022). Besides consumptive and industrial use, groundwater extracted through tube wells, dug wells, springs and kareze is the principal source of irrigation water for orchards and field crops (Khair et al., 2021). Balochistan is the least water-secure province. It has a total available water of 27.400 m3 per year and per capita water availability is 560 mm per year (Ahmad, 2006). As to the minimal water availability and inefficient irrigation methods, out of the total area of the province, only 5.9 percent of the area is under cultivation in Balochistan. The area under cultivation can be increased with the use of improved irrigation techniques (Pfeiffer and Lin, 2014; Kabbur et al., 2020). The province has an annual mean rainfall of 200-250 mm and the crop water requirement of the major high delta crops, i.e. apple and apricot, is 1200 mm, which is five times more than the mean rainfall. The associated shortfall is met by groundwater extraction (IUCN, 2006).

Groundwater is one of the most common pool resources in major areas of the world because of its public good nature and it is under severe pressure due to conventional irrigation methods (Muñoz-Arriola et al., 2021). It is non-excludable and without a strong institutional setting, it is difficult to exclude water users from pumping water from aquifers (Rana et al., 2021). In highland Balochistan, the result of the tubewell surge and public property nature yields the extraction of groundwater faster than its replenishment (Jamil and Mahmood, 2024). Dealing with prevailing groundwater depletion, cultivation of crops requiring less irrigation water and irrigation methods with higher efficiency are highly needed at the time (Razzaq et al., 2018).

Similarly, Balochistan is confronting an alarming decline in the groundwater table (Akhtar et al., 2021), due to climatic variation and inadequate groundwater supervision, at a pace of more than 10-40 feet per year in three major basins: The Pishin Lora Basin (PLB), the Zhob River Basin (ZRB) and the Nari River Basin (NRB) (Ashraf and Hassan, 2020). In the period of 40 years, the overall decline reported in the water table is from 50-100 feet to around 1200-1500 feet in the highlands (Quetta, Kuchlak), which is a tremendous example of overexploitation of groundwater resources (Jamil and Mahmood, 2024). Out of 18 basins in Balochistan, ten are over-exhausted (Rana et al., 2021). All 18 basins in Balochistan have extracted nearly 60 percent of their groundwater. With the current rate of groundwater depletion, Ahmad, (2006) believed that future water scarcity could lead to major intergenerational sustainability and survival issues and serious water disputes between residents of different basins. Drip irrigation systems are the most often utilized HEIS for water saving in orchards in highland Baluchistan (Khoso et al., 2022). It is regarded as the most effective irrigation system, increasing irrigation water use efficiency by 98% (Bakhsh et al., 2015), crop yields by 100% (Anjum et al., 2014), and reducing agro-fertilizer consumption by 25% (Vija-yakumar et al., 2010). It is ideal for growing high-value crops in orchards and tunnels. Tunnel farming with drip irrigation may provide yearly revenues ranging from Rs. 1.24 to Rs. 1.98 million per acre (Bakhsh et al. 2015). Scholars have extensively studied drip irrigation (Chauhdary et al., 2015; 2017; 2019; 2020) to determine its benefits and adaptability for Pakistani conditions.

HEIS has significant potential to improve the lives of small farmers via the use of tunnel farming, which may greatly increase their profits compared to conventional techniques (Rana et al., 2024). By using HEIS, farmers may significantly boost their yearly net profits on small land holdings by cultivating high-value crops like vegetables and fruits. Since 2006, many governmental and non-governmental organizations, including the On Farm Water Management (OFWM) Department, the World Bank, FAO, ADBP, and BLEEF, have actively subsidized the HEIS in the region (Kahlown and Kemper, 2007).

Despite the several advantages and financial assistance offered by the government, the adoption rate of HEIS falls short of needs and expectations (Kahlown and Kemper, 2007; Qasim et al., 2022). The acceptance of this new irrigation product is being hindered by a range of obstacles including economic, societal, technological, marketing, and a lack of associated awareness (Madhava and Surendran, 2016). There are many examples where farmers initially install drip irrigation systems but subsequently leave them due to various causes, thus adversely affecting the adoption process of HEIS (Bakhsh et al., 2020). Despite a few instances of success, the majority of farmers are hardly managing their installed, improved irrigation HEIS. The government and policymakers are under pressure to investigate the factors impeding the adoption of HEIS. They are following ways to provide policy options to promote HEIS in order to help small farmers improve their crop yield (Government of Balochistan, 2022). Table 1 classifies the respondents into the different categories. This study aimed to identify the primary obstacles that hindered farmers in Balochistan, Pakistan, from adopting or giving up the use of drip irrigation systems. It also aimed to determine the challenges faced by farmers in transitioning to these modern irrigation systems. The study also aimed to examine the factors contributing to the lack of adoption of HEIS by conducting an extensive survey of farmers.

Table 1. Distribution of respondents in different basins of highland Balochistan.

Zone/Area	Category		
	Adopters of HEIS	Non-adopters of HEIS	Total
Pishin Lora Basin	18	36	54
Zhob River Basin	15	128	143
Nari River Basin	47	56	103
Total	80	220	300

METHODOLOGY

This study aimed to survey irrigation farmers, including adopters of High-Efficiency Irrigation Systems (HEIS) and non-adopters, in highland Balochistan, Pakistan. Baluchistan is characterized by six distinct agricultural zones that are categorized based on altitude and geography.

Figure 1 Depicts the six Geographical zones, including upper highland, highland, sub-highland, deserts, plains, and coastal zones. A key zone, highland, was purposively selected using a multistage sampling technique. Highland is therefore selected as it has high cultivation of fruits and vegetables crops and has the potential for groundwater revival. Three key basins, Pishin Lora Basin (PLB), Zhob River Basin (ZRB), and Nari River Basin (NRB), were chosen from eighteen basins. These basins were chosen for their importance in groundwater resource development, applcation of HEIS, and 60% cotribution to provincial revenue from fruit production.

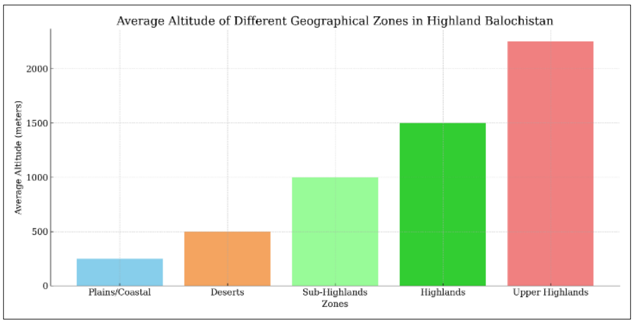

Figure 1. Geographical zones in Baluchistan; Source: Chaudhary et al. (2008), Rana et al. (2021).

The third stage selected the Loralai sub-basin from the Nari River Basin (NRB), the Killa Saifullah sub-basin from Zhob River Basin (ZRB) and the Kuchlak sub-basin from the Pishin Lora Basin (PLB). The final stage selected five sample villages from each sub-basin, with a representative sample of size 300 farmers utilizing a proportionate stratified sampling method. Primary data was collected using a pre-tested questionnaire.

Econometric Modelling

Statistical packages STATA version 17 was employed to analyze the impact of farmer age, education, credit facility, off-farm income, maintenance and operation, and lastly, the degree of water scarcity on the response variable, namely the adoption decision of HEIS. Binomial (or binary) logit regression was employed to investigate the study objectives. The logit regression has been widely used in several agricultural economic studies that call for the analysis and prediction of a dichotomous (binary) outcome such as adoption or non-adoption. It also helps in estimating the probabilities and linear combination of the predictors (Sanni and Doppler, 2007; Banerjee and Martin, 2009).

$$P_i\left(Y = \frac{1}{X_i}\right) = f(Z_i) = \frac{1}{1 + e^{-(\alpha + \beta_i X_i + \varepsilon_i)}} \quad (1)$$

Where; P_i = probability that a farmer is an adopter of HEIS in the face of explanatory variables (X_i) and P_i ranges between 0 to 1.

e = natural logarithm base, X_i = the vector of the independent variable, α and β_i = the model parameters to be estimated, and, ε_i = the stochastic error term.

This study focused on modeling the probability (Pi) of farmers adopting HEIS based on explanatory variables (Xi). The model estimates parameters αi and βi using the natural logarithm base (e). The odds ratio, which is the ratio of the probability of adopting HEIS (Pi) to not adopting (1 - Pi), is employed to interpret the estimated coefficients. This approach facilitates a clearer understanding of the factors influencing HEIS adoption. Thus;

$$e^{z_i} = \frac{P_i}{1-P_i} \quad (2)$$

$$\ln\left(\frac{P_i}{1-p_i}\right) = z_i \quad (3)$$

$$Z_i = \alpha + \sum_{1=0}^{n} \beta_i X_i + \varepsilon_i \quad (4)$$

By the introduction of a dichotomous response variable, Y_i, Yi = 1 if Y* > 0; 0 otherwise.

Y represents adoption, with 1 indicating adopters and 0 representing non-adopters. The goal is to solve Equation (01) to determine the probability of Y being 1, reflecting the likelihood of adoption. The equation helps calculate this probability based on the data and parameters. It enables an assessment of individuals' probability of becoming adopters in the study.

$$\left(\frac{P_i}{1-P_i}\right) = e^{z_i} \quad (5)$$

$$\text{Then, } P_i = \frac{e^{z_i}}{1+e^{z}} \quad (6)$$

RESULTS AND DISCUSSIONS

Table 2 provides an analysis of the social and economic factors that influenced the adoption of HEIS by farmers. According to the findings of the study, adopters, who had an average age of approximately 44 years, were significantly younger than non-adopters, who had an average age of approximately 47 years. It would appear from this that younger farmers were more willing to explore and implement new irrigation technologies. Educationally, HEIS adopters had studied nearly eight years of schooling, suggesting a connection between education and the willingness to adopt HEIS. A lower level of education may be associated with a reluctance to adopt higher education information systems (HEIS), as evidenced by the fact that non-adopters had an average of approximately six years of formal schooling.

Farm size also appeared to play a key role, with HEIS adopters typically managing larger farms than non-adopters. Despite this, the operational land holding was smaller for adopters, suggesting that efficiency gains through HEIS might be a driving factor for those with larger but less cultivated lands. Finally, the study showed that family size and fallow land were almost comparable between both groups, suggesting that these factors did not significantly influence the decision to adopt HEIS.

Table 3 reflects that the adoption of HEIS is significantly influenced by soil conditions in the highlands of Balochistan. Most farmers, irrespective of HEIS adoption, responded with moderate soil quality, but a greater number of non-adopters claimed to have fertile soil. Notably, HEIS adopters predominantly dealt with sandy and clayey soils, suggesting that farmers with challenging soil textures are more inclined to adopt HEIS. Salinity issues and slops of land were similar across both groups, suggesting these factors had less influence on the decision to implement HEIS. Land tenure, mainly consisting of owner-cultivated land, also showed little variation, indicating that land ownership status does not significantly impact HEIS adoption decisions. The study findings revealed soil quality and texture as key determinants in the adoption of efficient and improved irrigation practices.

Table 2. Socioeconomic characteristics of the respondents.

Socio-economic variables	Adopters of HEIS (N=80)				Non-adopters of HEIS (N=220)			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Age (years)	43.77	10.52	29.00	65.00	47.00	12.17	25.00	85.00
Education (years)	7.80	5.18	5.00	16.00	5.80	4.18	0.00	16.00
Family size (no.)	18.00	10.92	5.00	44.00	19.62	13.37	2.00	62.00
Farm size (acres)	44.75	55.79	5.00	210.00	34.83	32.17	4.00	230.00
Operational holding (acres)	10.33	12.89	3.00	55.00	15.47	14.90	3.00	120.00
Barren land (acres)	19.96	25.20	0.00	108.00	20.96	27.24	3.00	208.00

Table 3. Perceptions of the respondents about soil characteristics.

Soil quality	Adopters of HEIS N = 80		Non-adopters of HEIS N = 220	
	Freq.	Percent	Freq.	Percent
Poor	7.00	8.75	25.00	11.36
Moderate	46.00	57.50	143.00	55.00
Good	27.00	33.75	52.00	23.64
Total	80	100	220	100
Soil texture				
Sandy	47.00	58.75	113.00	51.36
Loamy	24.00	30.00	12.00	5.45
Clayey	8.00	10.00	90.00	40.91
Other	1.00	1.25	5.00	2.27
Total	80	100	220	100
Salinity problem				
Yes	14.00	17.50	36.00	16.37
No	66.00	82.50	184.00	83.63
Total	80	100	220	100
Land slop				

Flat	25.00	31.25	71.00	32.27
Sloppy	55.00	68.75	149.00	67.73
Total	80	100	220	100
Land cultivated by				
Owner	66.00	82.50	164.00	74.55
Tenant	3.00	3.75	2.00	0.91
Owner + Tenant	1.00	1.25	0.00	0.00
Share cultivated	10.00	12.50	54.00	24.55
Total	80	100	220	100

Figure 2 explores the perceptions of HEIS and related government policies across different river basins (PLB, ZRB, NRB). When the farmers were asked about conducting soil tests before HEIS installation, a majority in all regions over 59 percent in PLB and 60% in both ZRB and NRB had not conducted soil tests, with a small fraction of 4.09% in PLB and around 10 percent in ZRB. There was a division in the responses regarding the impact of HEIS on crop yields. In the ZRB, 55 percent of farmers believed that yields had increased, while in the NRB, about 52.5% of farmers said that yields had somewhat increased. Conversely, in the PLB, the largest group, 43.64% of farmers, were uncertain about the impact of HEIS on crop yields.
Regarding the comparison of HEIS with traditional flood irrigation, a majority in the ZRB 65% and NRB 60% preferred HEIS, while in the PLB responses, 36.36% of farmers preferred HEIS and 59.55% of farmers did not favor HEIS. Lastly, awareness of HEIS and government subsidies was notably low across all regions, with the highest level of awareness at a mere 5% in the NRB. This highlights a significant gap in knowledge dissemination regarding HEIS and potential government support for such technologies.

Adopters' Perceptions about the Constraints of HEIS Adoption

Figure 3 shows that in the Pishin Lora Basin, 97% of respondents identified backup repair and maintenance (R&M) as a major barrier. The authors conducted this study in Highland Balochistan to investigate the challenges faced by adopters and non-adopters of HEIS in three distinct basins: Pishin Lora Bain, Zhob River Basin, and Nari River Basin. The results were expressed as percentages, indicating the proportion of respondents who identified specific constraints.
Electricity issues were also prevalent, with 77% of participants indicating this as a constraint. The lack of technical knowledge concerned 80%, while absentee farm ownership affected 30% of respondents. Financial constraints were almost universal, with 99% reporting this issue. 43% of respondents reported operational difficulties. However, the Zhob River Basin showed a similar pattern of constraints with some variations. A shocking 91% of participants reported inadequate backup repair and maintenance (R&M). The percentage of respondents who reported electricity challenges was 66 percent, a figure slightly lower than that of the Pishin Lora Basin survey. 71% of respondents encountered difficulties due to insufficient technical knowledge. Absentee ownership was a lesser concern, accounting for 20%. Financial constraints were nearly as prevalent as in the Pishin Lora Basin, with 92% indicating them as barriers. Finally, 81% of respondents reported that operating the equipment of the HEIS is a complex procedure. Survey findings are consistent with the study results of Bakhsh et al. (2020).

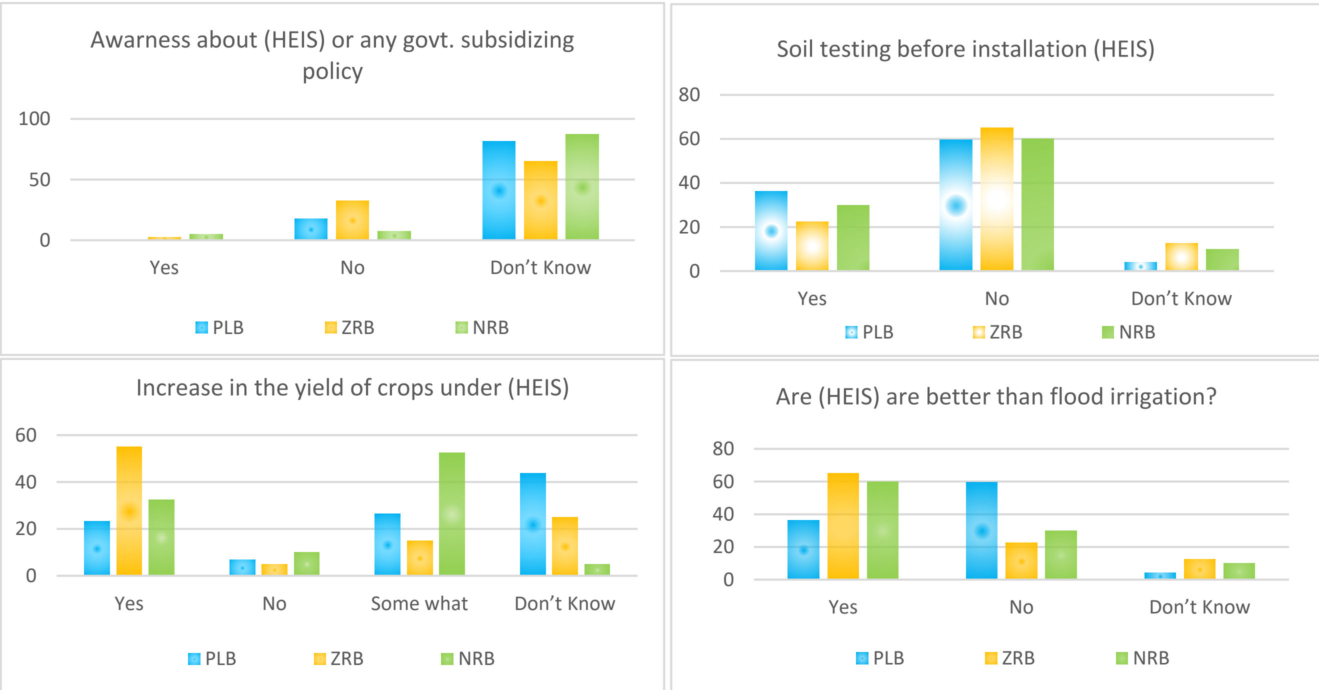

Figure 2. Perceptions of the respondents about distinct entities relating HEIS; Source: field survey (2023).

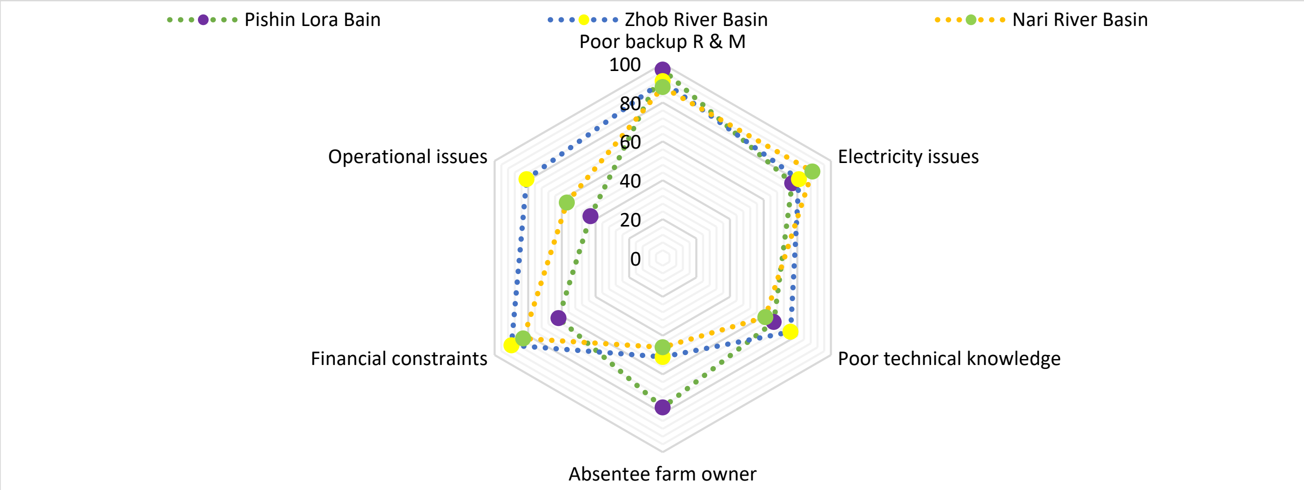

Figure 3. Constraints faced by adopters of HEIS; Source: field survey (2023).

Finally, the constraints in the Nari River Basin were similar to those in the other two basins, though to varying degrees. Poor backup R&M concerned 88% of respondents, slightly less than in the other basins. Electricity issues were significantly more prevalent, affecting 89%. This basin had the highest percentage of respondents 91% who claimed a lack of technical knowledge as a constraint. Absentee farm ownership had a larger impact here, accounting for 56%. Nearly all respondents reported financial constraints 96%. About 35% of respondents expressed less concern about operational issues. The adoption of HEIS in highland Balochistan faces numerous challenges, including financial constraints, inadequate technical knowledge, and systemic issues in electricity supply and maintenance services. The variation in these constraints highlights the need for targeted interventions to address the specific needs of each basin.

Non-adopters' Perceptions about the Constraints of HEIS Adoption

Figure 4 reflects that non-adopters of HEIS in the Pishin Lora Bain, Zhob, and Nari River Basins of highland Balochistan face several barriers, with lack of knowledge and maintenance being the most common. Farmers in highland Balochistan's Pishin Lora Bain, Zhob, and Nari River Basins face several barriers to adopting HEIS, with lack of knowledge and maintenance being the most common. Poor repair services cause almost all respondents 97% of Pishin Lora Bain to struggle with system maintenance, and 99% report financial issues as a major barrier, indicating that the costs associated with HEIS pose a significant constraint. Unreliable electrical supply is a matter of concern for 77% of farmers, and 80% of farmers feel they lack the technical expertise to effectively implement HEIS. Similar issues persist in the Zhob River Basin, though 81% of the farmers reported operational difficulties, possibly due to the area's unique environmental or economic conditions. Financial and technical knowledge barriers are slightly lower than in Pishin Lora Bain but remain high, affecting 92% and 71% of farmers, respectively.

In the Nari River Basin, 88% of non-adopters identified poor backup R&M as a major constraint, which is consistent with the overall trend of maintenance-related challenges. Electricity issues were significantly higher in this basin, affecting 89% of respondents, indicating more severe infrastructural problems. A large portion (91% of the farmers) reported a lack of technical knowledge, the highest of the three basins, highlighting the critical need for HEIS education and training. Absentee farm ownership was more common in this basin at 56%, indicating a significant impact on HEIS adoption. As in the other basins, 96% of respondents reported financial constraints in this basin too. However, operational issues were less important in this case, accounting for 35%. The survey results are consistent with the findings of (Bakhsh et al., 2020). These findings show that non-HEIS adopters in these regions face a number of challenges that prevent HEIS adoption. The most notable of these are financial constraints, a lack of technical knowledge, and infrastructure challenges such as inadequate backup R&M and power outages. Given the varying severity of these challenges across basins, interventions to encourage HEIS adoption must be designed to each basin's unique needs and circumstances.

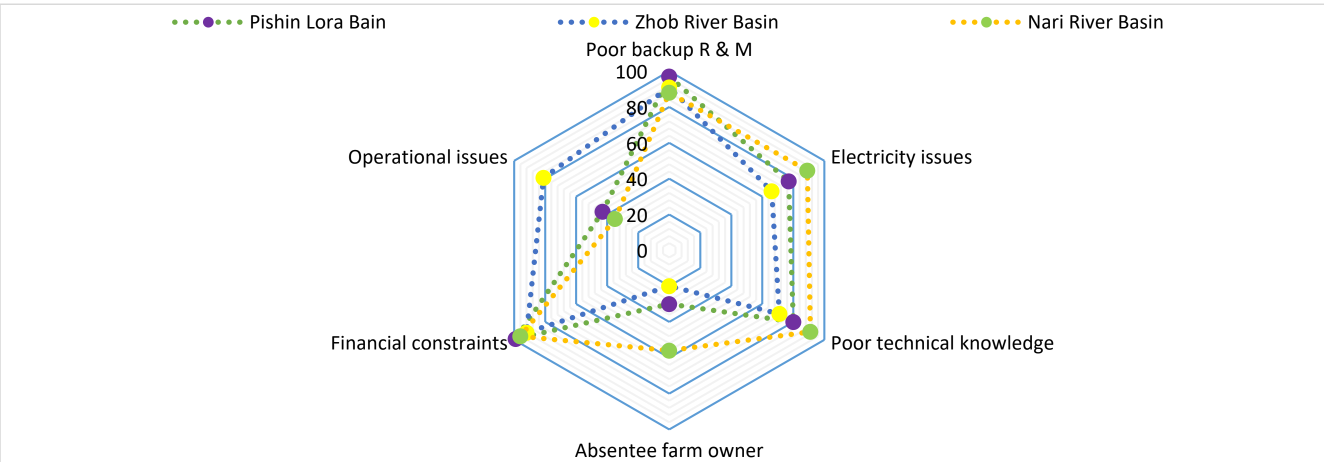

Figure 4. Constraints faced by Non-adopters of HEIS; Source: field survey (2023).

Factors Affecting the Adoption of HEIS (Logistic Estimates)

Table 4 depicts the econometric analysis which provides a detailed examination of determinants that influence the adoption of new irrigation technologies. The study's findings emphasize the significance of farmer demographics, education levels, economic circumstances, soil characteristics and environmental burdens in influencing adoption decisions, providing a picture of the dynamics in highlands Baluchistan. Among socioeconomic factors, the study discovered that farmers aged 30-59 are more likely to adopt high-efficiency irrigation systems. A statistically significant coefficient value of 13.096 supports this trend among middle-aged farmers, which can be attributed to their experience and openness to new ideas. Similarly, educated farmers up to graduation are more likely to adopt technology, according to a positive but statistically non-significant coefficient of 3.649 at the conventional probability level, implying that higher education levels may improve access to information and technological knowledge, increasing the likelihood of adoption. The findings of studies by Fakoya et al. (2007) and Bakhsh et al. (2020) also showed that mature and educated farmers tend to be more resource-efficient and inventive.

Economic factors were also identified as significant determinants, with off-farm income positively associated with HEIS adoption. The coefficient of 3.984 for off-farm income indicates that financial flexibility, possibly resulting from additional income, encourages farmers to invest in advanced irrigation systems. This economic dimension contributes to our understanding of the adoption process by emphasizing financial security in technology adoption. The survey results are consistent with the findings of Razzaq et al. (2018).

Environmental factors, such as water scarcity and soil texture, also influence adoption decisions. The sandy soil, with a coefficient of.038, indicates that high-efficiency irrigation systems are ineffective in these areas, creating a significant barrier. On the other hand, the ongoing problem of water scarcity, as demonstrated by a coefficient of 0.246, emphasizes the urgent need for sustainable water management strategies. This compels farmers to use more effective irrigation methods to mitigate the negative effects of water scarcity. The study of Bakhsh et al. (2020) revealed similar results.

Collectively, these findings paint a complete picture of the interrelated socioeconomic, technical, and environmental factors that influence HEIS adoption in Baluchistan's highland region. The Adoption rates in all three basins are different because of different socioeconomic factors. Lastly the study not only provides valuable insights for policymakers and stakeholders advocating sustainable agricultural practices by revealing the complexities of these impacts, but it also emphasizes the complex web of determinants that must be addressed to improve technology adoption in resource-poor areas.

Table 4. Logistic estimates of different factors influencing the adoption of HEIS (N =300).

Explanatory Variables	Coef.	St. Err.	t-value	p-value	[95% Conf.	Interval]	Sig
Farmer's age (years)	13.10	7.59	4.44	0.00	4.21	40.75	***
Farmer's education							
Primary (up to 5 years)	1.55	1.38	0.49	0.63	0.27	8.92	
Matriculation (up to 10 years)	1.66	1.63	0.51	0.61	0.24	11.40	
Graduate (up to 16 years)	3.65	2.76	1.71	0.09	0.83	16.04	*
Off-farm income (Rs)	3.98	3.10	1.78	0.08	0.87	18.28	*
Soil texture :							
Sandy	0.04	0.04	-3.05	0.00	0.01	0.31	***
Other	0.31	0.39	-0.94	0.35	0.03	3.55	
Owner presence/visits							
Weekly	0.63	0.34	-0.86	0.39	0.22	1.80	
Monthly	0.88	0.76	-0.15	0.88	0.16	4.75	
Maintenance (0=no, 1=yes)	0.72	0.78	-0.30	0.76	0.09	5.92	
Farm credit (0=no, 1=yes)	1.44	0.75	0.71	0.48	0.53	3.97	
Degree of water scarcity (0=no, 1=yes)	0.25	0.15	-2.31	0.02	0.08	0.81	**
Constant	0.02	0.03	-2.66	0.01	0.00	0.36	***
Average dependent var	0.17	SD. dependent var				0.38	
R-squared (Pseudo)	0.382	Total number of observations				300	
Chi-square	71.12	Probability > chi2				0.00	
Akaike crit. (AIC)	141.12	Bayesian crit. (BIC)				184.13	

* p<.1, ** p<.05, *** p<.01.

CONCLUSIONS AND RECOMMENDATIONS

The research in three critical river basins in Balochistan sheds light on important factors of HEIS adoption. It emphasizes the role of characteristics such as farmer age, education level, and off-farm income in increasing adoption rates. However, adoption is restricted by constraints such as budgetary limits, operational concerns, owner presence, and power shortages. A planned approach concentrating on eliminating these barriers through targeted educational programs, technical support, and easily available financial aid is required. Such efforts may open the path for larger adoption of HEIS, which is vital for effective water management and agricultural sustainability in Balochistan's water-deficient regions. In highland Balochistan, promoting HEIS adoption requires effective community engagement and awareness campaigns. Utilizing local social media influencers and community networks can help create a welcoming environment for HEIS by emphasizing its economic and environmental benefits through real-life success stories. Improved outreach efforts by the government and NGOs are essential, with model farms demonstrating HEIS and better maintenance practices. Technical training and capacity building through targeted skill development initiatives at community centers and schools can address the technical knowledge gap, while collaborations with agricultural experts and NGOs ensure high-quality training for efficient HEIS use and maintenance. Additionally, localizing HEIS by manufacturing components and establishing service centers in rural areas will improve accessibility and reduce import dependence. Government incentives, such as tax cuts and start-up subsidies, could stimulate local manufacturing and support a continuous service network that includes training, maintenance, and repairs tailored to farmers' needs.

To address financial barriers, dynamic subsidy models can be introduced through government-supported microfinance programs, offering flexible low-interest loans to small-scale farmers. Promoting HEIS in market-oriented greenhouses for high-value crops, coupled with solar-powered drip irrigation, can enhance productivity, create jobs, and ensure energy reliability. Renewable energy integration through subsidized solar power for HEIS aligns with global sustainability trends, providing long-term benefits. Public-private partnerships (PPP) can also play a crucial role in value chain enhancement by offering comprehensive training on best management practices, irrigation scheduling, processing, and marketing strategies suited to local conditions. Establishing agro-processing zones under PPPs will improve storage, handling, and marketing for small farmers, enabling access to remote markets and boosting revenues. Lastly, a robust monitoring and evaluation framework involving local stakeholders is necessary for adaptive management, ensuring continuous improvement of HEIS projects in the dynamic agricultural landscape of highland Balochistan.

Declaration of Competing Interest

I declare that I have no competing interest with anyone that may influence the research work published in this paper.

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