

The Nexus of Socioeconomic, Technological and Environmental Factors Influencing the Adoption of High-Efficiency Irrigation Systems (HEIS): A Case Study of the 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-Efficiency 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. 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.

Keywords: Adoption, Water scarcity, Groundwater aquifers, Water Use Efficiency (WUE), High-Efficiency Irrigation Systems (HEIS), Logistic regression

1 INTRODUCTION

Flooding, a widely practices irrigation method used by farmers in Baluchistan, Pakistan, has an irrigation water efficiency of lower than 50% [1, 2]. Such low irrigation efficiency is a key barrier to achieve potential output and leads to the injudicious use of groundwater resources [3]. Uneven fields and ineffective farm design lead to 25% of irrigation water wastage during application [4]. 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 [5].

Balochistan is an arid, dry mountainous region [6]. 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 [7] 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 [8]. 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 [9, 10]. 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 [11]

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 [12]. It is non-excludable and without a strong institutional setting, it is difficult to exclude water users from pumping water from aquifers [13]. In highland Balochistan, the result of the tubewell surge and public property nature yields the extraction of groundwater faster than its replenishment [14]. Dealing with prevailing groundwater depletion, cultivation of crops requiring less irrigation water and irrigation methods with higher efficiency are highly need of the time [5].

Similarly, Balochistan is confronting an alarming decline in the groundwater table [15], 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) [32]. 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 [14]. Out of 18 basins in Balochistan, ten are over-exhausted [13]. All 18 basins in Balochistan have extracted nearly 60 percent of their groundwater [16]. With the current rate of groundwater depletion, [8] 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 [17]. It is regarded as the most effective irrigation system, increasing irrigation water use efficiency by 98% [18], crop yields by 100% [19], and reducing agro-fertilizer consumption by 25% [20]. 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 [18]. Scholars have extensively studied drip irrigation [21, 22, 23, 24] 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 [25]. 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 [26]. Despite the several advantages and financial assistance offered by the government, the adoption rate of HEIS falls short of needs and expectations [6, 26]. 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 [27]. 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 [3]. 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 [28].

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. The farmers were classified into the following categories:

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 |

2. MATERIALS AND METHODS

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.

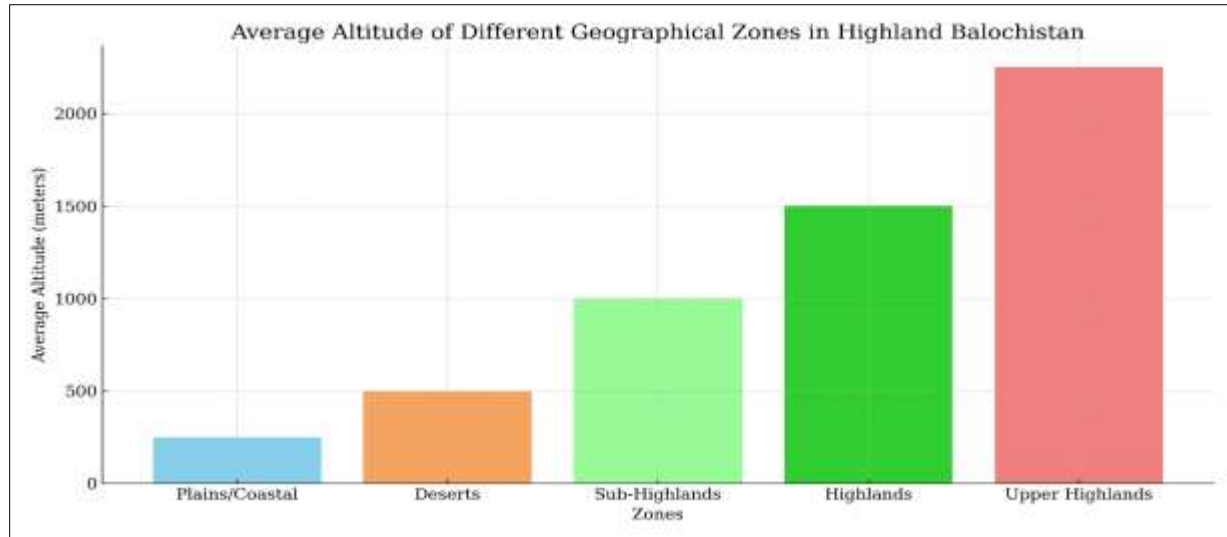


Figure. 1. Geographical zones in Baluchistan

Source (Chaudhary et al., 2008) [33]

Balochistan has six agro-ecological zones based on elevation, including upper highland, highland, sub-highland, deserts, plains, and coastal zones. A key zone, highland, was purposively selected using a multistage sampling technique. 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, application of HEIS and 60% contribution to provincial revenue from fruit production. 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.

2.1 Econometric modeling

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 outcome such as adoption or non-adoption [30, 31].

$$P_i(Y = 1/X_i) = f(Z_i) = \frac{1}{1 + e^{-(\alpha + \beta_i X_i + \epsilon_i)}} \dots \dots \dots (01)$$

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 (P_i) of farmers adopting HEIS based on explanatory variables (X_i). The model estimates parameters α_i and β_i using the natural logarithm base (e). The odds ratio, which is the ratio of the probability of adopting HEIS (P_i) to not adopting ($1 - P_i$), is employed to interpret the estimated coefficients. This approach facilitates a clearer understanding of the factors influencing HEIS adoption.

Thus,

$$e^{Z_i} = \frac{P_i}{1-P_i} \dots \dots \dots (02)$$

$$\ln\left(\frac{P_i}{1-P_i}\right) = z_i \dots \dots \dots (03)$$

$$Z_i = \alpha + \sum_{i=0}^n \beta_i X_i + \varepsilon_i \dots \dots \dots (04)$$

By the introduction of a dichotomous response variable, $Y_i, Y_i = \begin{cases} 1 & \text{if } Y^* > 0 \\ 0 & \text{otherwise} \end{cases}$

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.

$$\left(\frac{P_i}{1-P_i}\right) = e^{z_i} \dots \dots \dots (05)$$

$$\text{Then, } P_i = \frac{e^{z_i}}{1+e^{z_i}} \dots \dots \dots (06)$$

3. RESULTS AND DISCUSSIONS

The following table 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 2 Socioeconomic characteristics of the respondents

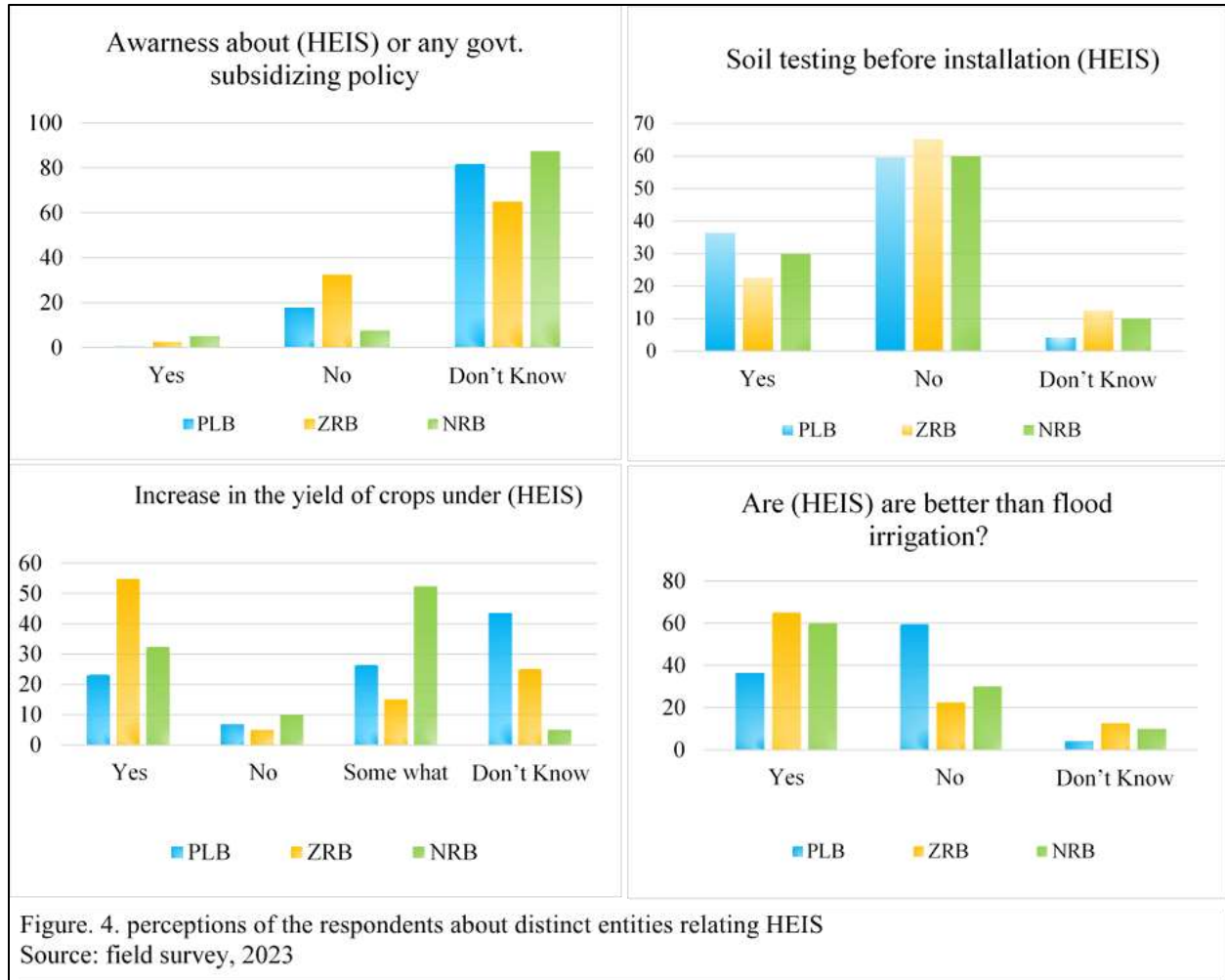
| Socio-economic variables | Adopters of HEIS (N=80) | | | | Non-adopters of HEIS (N=220) | | | |
|------------------------------------|-------------------------|-----------|-------|--------|------------------------------|-----------|-------|--------|
| | Mean | Std. Dev. | Min | Max | Mean | Std. Dev. | 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 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 slopes 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 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 4 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.



3.1 Adopters’s perceptions about the constraints of HEIS adoption

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.

Figure 3 shows that in the Pishin Lora Basin, 97% of respondents identified backup repair and maintenance (R&M) as a major barrier. 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. The Zhob River Basin showed a similar pattern of constraints, however, 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 that was slightly lower than that of the Pishin Lora Basin survey. A significant number 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 [3].

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.

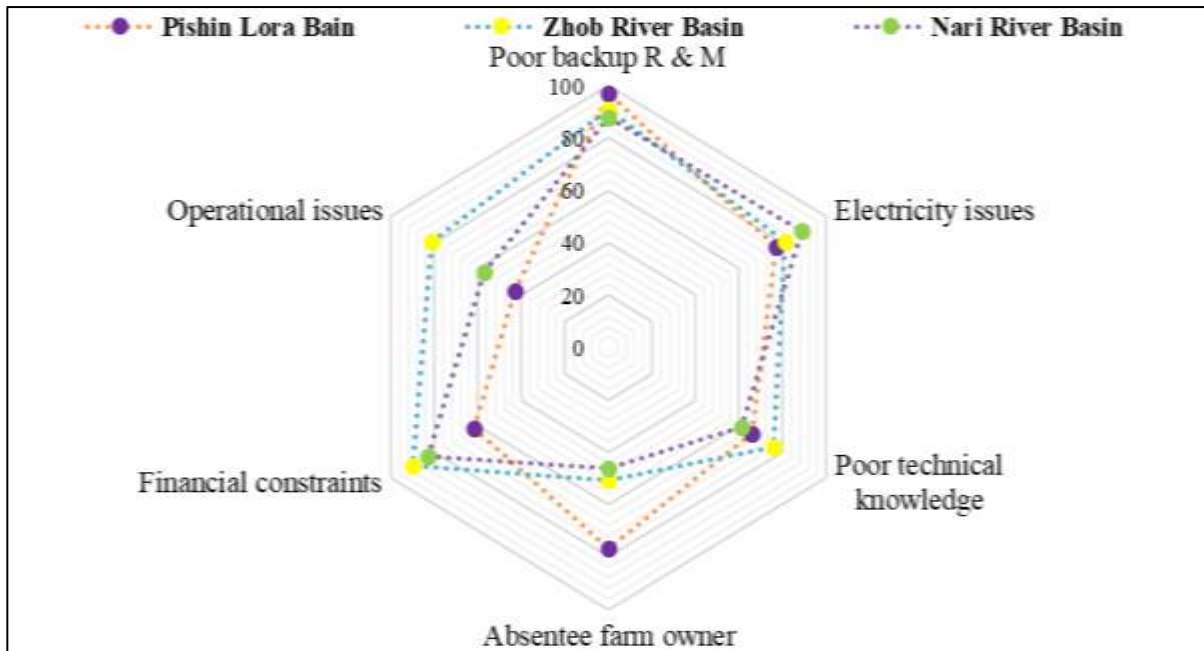


Figure 3. Constraints faced by Adopters of HEIS

Source: field survey, 2023

3.2 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% in 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 [3]. 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.

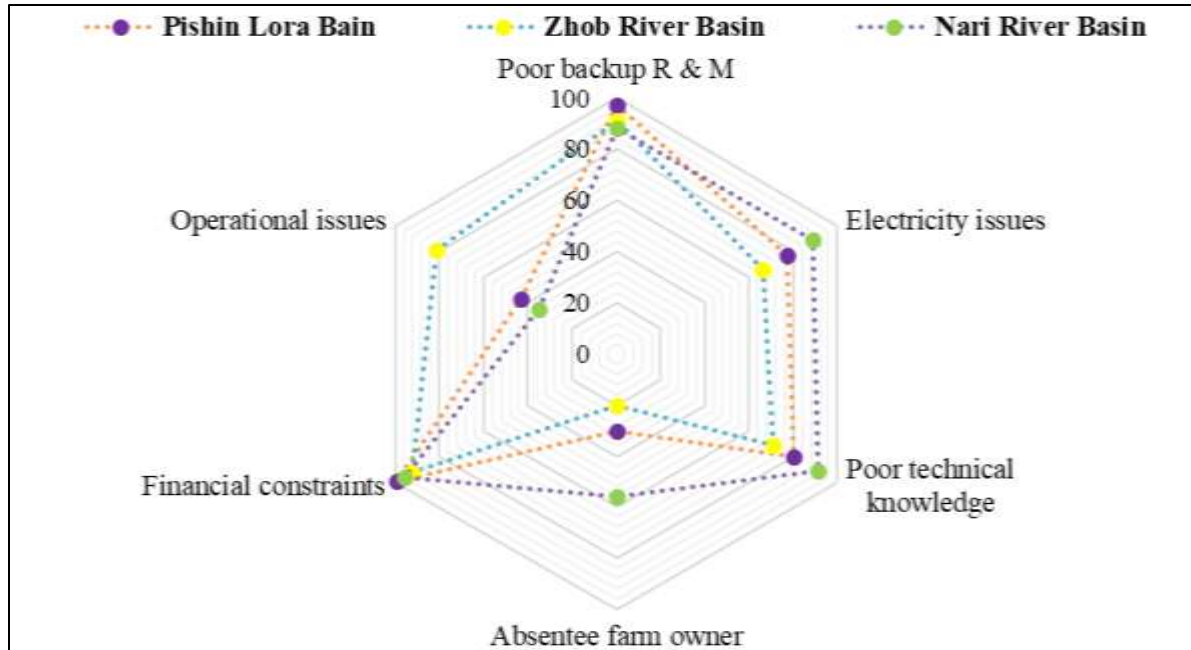


Figure. 2. Constraints faced by Non-adopters of HEIS
Source: field survey, 2023

3.3 Factors affecting the adoption of HEIS (Logistic estimates)

The econometric analysis 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 [3, 29] 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 [5].

Environmental factors, such as water scarcity and soil texture, also influence adoption decisions. The sandy soil, with a coefficient of 0.038, 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 [3] revealed similar results.

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 | | | | | | | | |
| 1) Primary (up to 5 years) | 1.55 | 1.38 | 0.49 | 0.63 | 0.27 | 8.92 | | |
| 2) Matriculation (up to 10 years) | 1.66 | 1.63 | 0.51 | 0.61 | 0.24 | 11.40 | | |
| 3) 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 : | | | | | | | | |
| 1) Sandy | 0.04 | 0.04 | -3.05 | 0.00 | 0.01 | 0.31 | *** | |
| 2) Other | 0.31 | 0.39 | -0.94 | 0.35 | 0.03 | 3.55 | | |
| Owner presence/visits | | | | | | | | |
| 1) Weekly | 0.63 | 0.34 | -0.86 | 0.39 | 0.22 | 1.80 | | |
| 2) 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 | | |

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

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 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.

4. CONCLUSION

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.

5. RECOMMENDATIONS

5.1 Community engagement and awareness campaigns

In highland Balochistan, where farmers often lack education and access to information, effective HEIS dissemination is essential. Using local social media influencers and community networks to promote HEIS can create a more welcoming environment. These campaigns should emphasize HEIS's long-term economic and environmental benefits, using real-life success stories to inspire trust and interest. The government and NGOs need to significantly improve their current outreach efforts, given the need for model farms demonstrating HEIS and their inadequate maintenance by the agricultural department. Addressing these gaps is critical for encouraging the adoption of HEIS in a way that is understandable and relevant to the local farming community.

5.2 Technical training and capacity building

Targeted training activities for skill development can help narrow the technical knowledge gap. These initiatives can reach a bigger audience by using existing community centers and schools as training facilities. Collaborations with agricultural professionals and non-governmental organizations (NGOs) can assure high-quality and appropriate training, equipping farmers to efficiently use and maintain HEIS.

5.3 Localized manufacturing and service network

Highland Balochistan should localize HEIS to improve accessibility and efficiency. This involves manufacturing drip irrigation-related components locally and developing service centers in rural areas. Government actions, such as tax cuts and start-up subsidies, may stimulate local manufacturing, reducing import reliance and making HEIS more accessible. These service centers will also provide continuous assistance, such as training, maintenance, and repair services targeted to farmers' specific needs. This method benefits the area economy while maintaining HEIS's long-term functioning and flexibility to the region's specific agricultural circumstances.

5.4 Subsidized and flexible financial models

Considering the poverty and the subsidy rate already given for adopting HEIS in the region, there is a dire need for a dynamic subsidy model. This can be achieved through government-supported microfinance programs, offering low-interest loans with flexible repayment terms tailored to small-scale farmers. Collaboration with local banks and microfinance institutions can ensure accessibility and proper implementation. To effectively reach the target population, local agricultural offices should heavily advertise and make these programs accessible.

5.5 HEIS-based smart and enhanced farming

HEIS should be promoted in market-oriented greenhouses for high-value fruits and vegetable crops because of their cheap cost and rapid revenue in off- and on-seasons, motivating growers to maintain them properly. Solar-powered drip irrigation for tunnel farming may boost output and provide job possibilities for rural youngsters, with proper marketing and training at demonstration farms.

5.6 Renewable energy integration

As per the study findings, the majority of the farmers were reluctant to adopt HEIS due to poor electricity (3/24 hours), so there is a need to integrate solar power to address the dual issues of energy scarcity and sustainability. Government initiatives can support subsidizing solar panels and related equipment. This strategy not only provides a reliable power source for HEIS but also aligns with global trends toward renewable energy, ensuring long-term environmental and economic benefits.

5.7 Public-private partnerships for value chain enhancement

A public-private partnership (PPP) joint venture is needed to provide comprehensive training for growing value-adding vegetables and fruits using ISO-certified best management practices, including irrigation scheduling, processing, packing, storage, and transportation in the value chain. Prioritize marketing efforts in places where HEIS is more possible due to climate, soil, and water conditions, rather than focusing just on meeting targets.

5.8 HEIS-driven agro-processing zones

To address the severe lack of storage, handling, sorting, packing, valuation, and purchase of farmers' food in highland Balochistan, PPP should establish agro-processing zones. Small-scale farmers would benefit from increased access to remote export markets. Collective processing and marketing will reduce costs while increasing profits. Adopting high-value crop production practices with HEIS (drip irrigation) in water-scarce areas can boost farmers' revenues. It will

be especially useful in areas where surface drip irrigation systems are unable to meet crop water requirements during the hot summer months, while also taking into account site-specific soil and water conditions.

5.9 Monitoring and evaluation for the continuous improvement of HEIS projects

A systematic monitoring and evaluation framework enables the tracking of progress and the identification of areas for improvement. Engaging local stakeholders in this approach ensures that input is meaningful and based on real-world experiences. This constant evaluation allows adaptive management, which is critical for the changing agricultural environment 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

Acknowledgment

We are thankful to all the respondents, the research team and the Agriculture department who supported us in this research work. We are thankful to Dr. Khalid Mushtaq (late) for his kind supervision in this research work.

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