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Identifying Determinants of Adopting Solar Pump Irrigation in Rice Cultivation: A Climate Smart Adaptation Strategy

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ABSTRACT

Solar pump irrigation (SPI) can be a game-changing phenomenon in the Bangladesh irrigation sector through its wider adoption among the farmers. The objectives of this study were to assess the rate of SPI adoption and the contributing factors of adopting solar pump irrigation in rice cultivation. The study was conducted with 108 randomly selected farmers in Maheshpur upazila under Jhenaidah district, Bangladesh. A pre-tested interview schedule was developed to collect data from the selected respondents. Data were analyzed through mean, percentage, frequency, standard deviation, and multinomial logistic regression. The interview survey revealed that the highest proportion (72.2%) of respondents did not adopt SPI, while 11.1% and 16.7% adopted it fully and partially, respectively. The inferential analysis revealed that family labor availability, land ownership status, on-farm income, and attitude towards SPI significantly influence farmers' non-adoption of SPI. Again, level of education, family labor availability, on-farm income, and off-farm income significantly influenced farmers' partial adoption of SPI. Initiatives to improve farmers' knowledge and foster a favorable attitude towards SPI might help promote the widespread adoption of this climate-smart strategy throughout the country.

Keywords: Rice cultivation, solar pump irrigation, adoption, climate smart practice, multinomial logistic regression

1. INTRODUCTION

Renewable energy sources provide a sustainable and environmentally friendly substitute for fossil fuels, which are limited and worsen environmental conditions. Solar-powered irrigation systems refer to irrigation setups driven by solar energy. The systems utilize photovoltaic (PV) panels, commonly known as solar panels, to capture solar energy and convert it into electricity. According to Limu (2023), this electricity then powers irrigation water pumps, providing a reliable and sustainable energy source for agricultural water management. Particularly in regions with abundant sunlight, rice farming has increasingly adopted Solar Powered Irrigation (SPI) as a practical and cost-effective solution (Limu *et al.*, 2025). As the approach is environmentally sound and uses renewable, clean energy, it is considered a climate-

smart agricultural technology. Kabir (2026) notes that worldwide adoption of SPI for rice farming has been increasing.

Bangladesh has a lot of potential for producing electricity using solar power. As a subtropical nation, the nation enjoys enough sunlight. Thus, using solar panels to capture sunlight is essential. Bangladesh is located in an area that is suitable for gathering solar energy, between 20.30° and 26.38° north latitude and 88.04° and 92.44° east longitude (Uddin et al., 2018). The average long-term sunlight statistics for Bangladesh show that, excluding the rainy and winter seasons, the amount of time spent in bright sunshine varies throughout the year from four to eleven hours. Podder and Islam (2015) reported that solar insolation in Bangladesh ranges from 4 to 6 kWh/m²/day, with the highest values occurring in the summer months. Owing to its geographic location, which provides more than 300 bright days annually, Bangladesh can potentially collect over 250 trillion kWh of solar energy (PSRB, 2017). The chances for using solar energy in Bangladesh are significantly greater than those of other renewable energy sources.

Rice is the major food crop in Bangladesh covering about 75% of total agricultural land (BBS, 2025). Three types of rice, namely Aus, Aman, and Boro, are cultivated during the summer and winter seasons. Irrigation is one of the important factors that influence the achievement of the desired yield. In most cases, it is difficult to provide continuous irrigation to rice fields using traditional irrigation systems. SPI can be a good alternative to reduce the problem. SPI uses renewable energy (sunlight) to gain energy for providing irrigation. Therefore, it does not harm the environment, which is not the case with fossil fuel-based irrigation. Due to the multipurpose social, economic, and environmental benefits of SPI, the system is considered a climate-smart adaptation strategy.

Past research on SPI use in Bangladesh focused on various aspects to understand its potential environmental benefit, scope to utilize extra energy, irrigation cost, co-benefit, etc (Dev, 2014; Hossain *et al.,* 2022; Buisson *et al.,* 2024). Very few studies have been conducted to understand the level of SPI adoption at the farm level and the determinants influencing farmers' decisions to adopt this approach. In this context, the present study has been undertaken to fulfill objectives such as assessing the status of solar pump irrigation use in rice cultivation, describing the selected characteristics of farmers, and identifying the factors contributing to its adoption.

2. MATERIALS AND METHODS

2.1. Locale of the Study

The research was carried out in Maheshpur Upazila, which is situated in Jhenaidah District of Bangladesh. Maheshpur is positioned at 23.3500°N 88.9125°E and encompasses a total area of 419.53 km², with 41,995 household units (Figure 1). This district contains six upazilas, and Maheshpur upazila was chosen purposively for the study. The upazila has 12 unions, and the Swaruppur union was selected purposefully as the study location. Two villages, Kushadanga and Hanifpur, were also purposively chosen as the study locale from the union.

2.2. Population and sampling

With the assistance of Sub-Assistant Agriculture Officers (SAAOs) and the Upazila Agriculture Office (UAO) in Maheshpur, the authors prepared two distinct lists of farmers from the selected villages. The two lists contained a total of 721 farmers, including 509 farm family heads from Kushadanga village and 212 from Hanifpur village, both of which were the study population. To conduct the study, a random sample of 108 farmers was selected, which represents 15% of the total number of farmers. The study applied multistage sampling to select the study areas and random sampling to select the respondents (farmers).

2.3. Data Collection

The sample farmers of the selected villages were personally interviewed by the researcher using a structured pre-tested interview schedule. The interview schedule or questionnaire was developed keeping the study objectives in mind. The questionnaire was divided into three parts, where the first and second parts highlighted farmers' socio-economic and farm management related characteristics. The third part covered farmers' use of SPI status. Prior to the data collection process, the researchers met with the local Sub Assistant Agriculture Officers (SAAOs) of the respective blocks to explain the study objectives and requested their help and cooperation in data collection.

2.4. Variables of the Study and their measurement

The study considered two types of variables, namely the dependent variable and the independent variables. The independent variables were farmers' selected characteristics such as age, educational qualification, family labor availability, farm size, land ownership status,

rice cultivation area, on-farm income, off-farm income, access to credit, agricultural extension contact, and attitude towards SPI. The dependent variable was the adoption of SPI by the farmers. The measuring techniques of these variables are mentioned in Table 1.

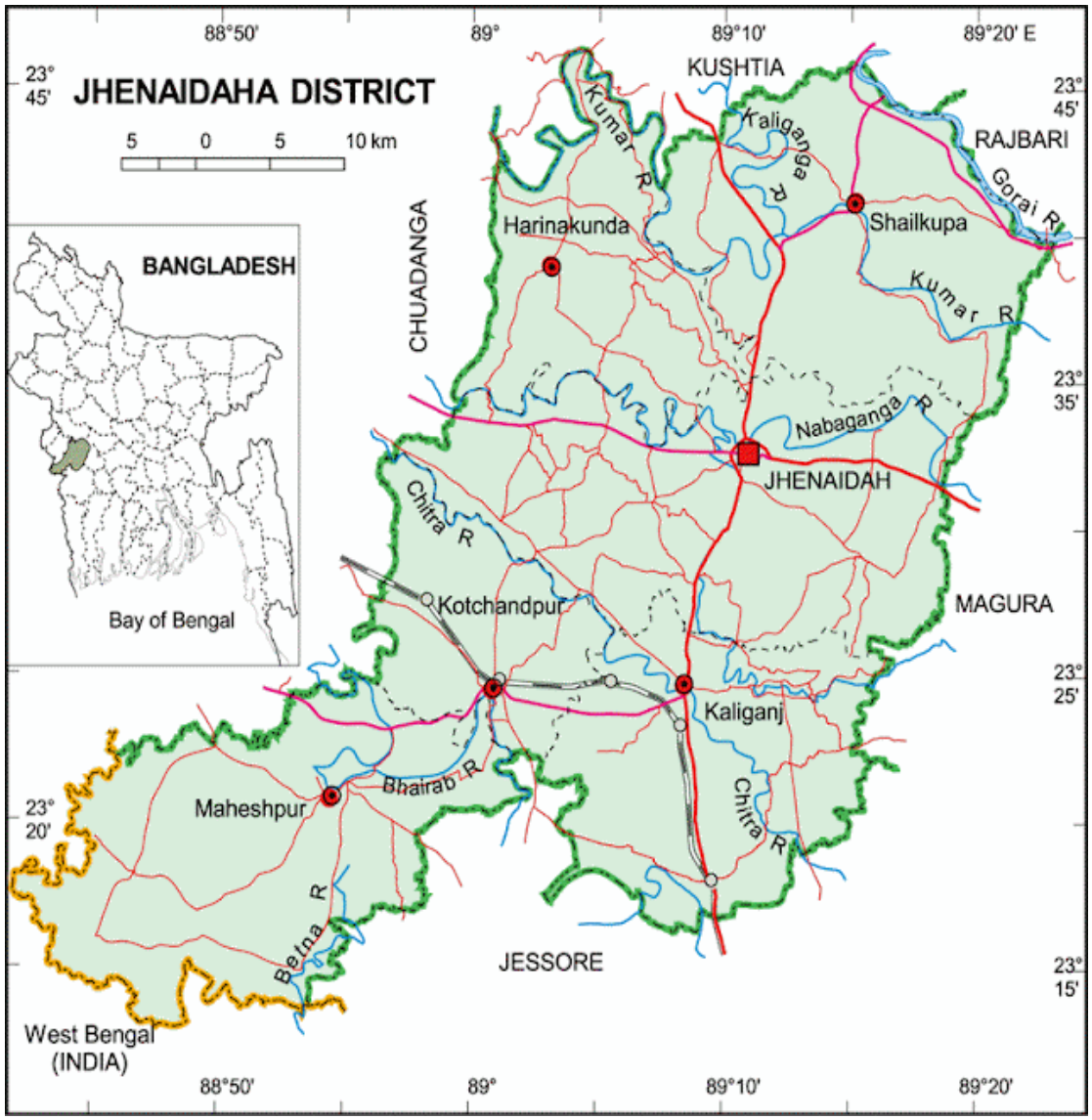

Figure 1. A Map of Jhenaidah District showing Maheshpur Upazila

Table 1. Measurement of dependent and independent variables

Variables	Measurement
Dependent variable	
Adoption of SPI	Full adoption, partial adoption and no adoption and the score was 2, 1 and 0 respectively.
Independent variables	
Age	Actual years from the birth to interview time.
Level of education	1 for 1 year of schooling
Family labor availability	Total number of family members engaged in farming
Farm size	Total land size of a farmer and expressed as 1 for 1 ha
Land ownership status	1 for leased farmers, 2 for mixed farmers, and 3 for land owners
Rice cultivation area	% of rice cultivation area out of total land area

On-farm income	Total annual income from agriculture in '000' BDT
Off-farm income	Total annual income other than agriculture in '000' BDT
Access to credit	The amount of credit received by a farmer in a year
Extension contact	Farmers' extent of contact with various media
Attitude towards SPI	Farmers' attitude towards SPI calculated on a Likert scale

2.5. Data Processing and Analysis

After data collection, we meticulously reviewed the gathered raw data to identify any inaccuracies or oversights. Necessary adjustments were made to overcome the inaccuracies. For qualitative data, appropriate scoring methods applied and assigned appropriate weights to each attribute to convert the data into quantitative formats. The independent and dependent variables were described using statistical measures such as range, mean, standard deviation, percentage, and frequency distribution. Multinomial logistic regression analysis was run to identify the significant selected characteristics on farmers' adoption of SPI. Statistical Package for Social Science (SPSS) software, version 20, was utilized for the analysis of data.

3. RESULTS

3.1. Adoption of Solar Pump Irrigation

The study observed three categories of SPI adoptions, namely, full adopters, partial adopters, and non-adopters. Full adopters are farmers whose entire rice land is irrigated by SPI, partial adopters are those who irrigate only a portion of their total agricultural land with SPI, and non-adopters are farmers who do not use SPI for irrigation in their paddy fields. Regarding the adoption of SPI, the respondents were scored on a scale ranging from 1 to 3, with an average score of 0.38 and a standard deviation of 0.68. Based on their score, the respondents were grouped into three categories, which are presented in Table 2.

Table 2. Distribution of Farmers according to their SPI adoption

Categorization	Basis of categorization	Respondents	
		Numbers	Percent
Adoption	3	12	11.1
Partial Adoption	2	18	16.7
Non-adoption	1	78	72.2
Total		108	100

According to the data presented in Table 2, the majority of respondents (72.2%) were non-adopters of SPI, followed by partial adopters (16.7%) and full adopters (11.1%), who used SPI to irrigate their land. The reason for non-adoption is possibly due to the unavailability of solar pumps near farmers' land or because they did not find it more beneficial than traditional irrigation methods. However, during the survey, researchers noted a positive attitude from most farmers who were interested in using SPI. Unfortunately, due to insufficient capacity of current solar pumps and inadequate availability of solar pumps as per the amount of land, only a few farmers could adopt SPI, and most farmers remained underprivileged with respect to SPI.

3.2. Characteristics of the Farmers

This part of the study discusses farmers' characteristics that are thought to be linked to their adoption of SPI. The characteristics are age, education level, family labor availability, land ownership status, rice cultivation area, on-farm income, off-farm income, access to credit, agricultural extension contact, and attitude towards SPI. On average, the farmers were middle-aged, had a primary educational background, and faced limited family labor availability. The majority of farmers reported higher family income from agricultural sources compared to non-agricultural sources. On average, they had a moderate level of credit access and extension contact. However, the majority of farmers had a favorable attitude towards the use of SPI in rice fields (Table 3).

Table 3. The salient features of the selected characteristics of the farmers

Characteristics	Measuring unit	Range		Mean	S.D.
		Possible	Observed		
Age	Years	-	18-75	44.11	11.323
Level of education	Year of schooling	-	00-15	4.3380	3.79611
Family labor availability	Members	-	00-3	.5741	.77585
Land ownership status	Score	1-3	1-3	2.2685	.71834
Rice cultivation area	Percentage	-	33-100	90.1707	13.80454
On-farm income	('000' Tk)	-	15-600	105.4907	99.75311
Off-farm income	('000' Tk)	-	00-350	94.1389	75.23315
Access to credit	('000' Tk)	-	00-100	14.6296	27.06606
Agricultural extension contact	Score	0-24	3-16	8.6389	2.21911
Attitude towards SPI	Score	0-40	16-37	31.1111	4.17902

3.3. Multinomial logistic regression to identify the factors of partial adoption and non-adoption of SPI

Table 4 presents the output of multinomial logistic regression analysis that was conducted to determine the factors that significantly contribute to farmers' adoption, partial adoption, and non-adoption of SPI. To conduct this analysis, a reference category was required, which could be any category. In this study, the adoption group was selected as the reference category. It is important to identify the reasons or factors responsible for the other two groups, i.e., partial adoptions and non-adoption. Therefore, the factors that influence farmers' partial adoption and non-adoption of SPI are highlighted below, considering the adoption group as the reference or base category.

3.3.1. Factors influencing non-adoption of SPI

Table 4. Parameter estimation result for the non-adoption of SPI

Independent Variables	β	S.E.	Wald	Sig.	Exp(β)
Age	.066	.053	1.545	.214	1.068
Level of Education	.188	.137	1.874	.171	1.207
Family labor availability	-1.711	.788	4.715	.030*	.181
Landownership status	1.540	.817	3.558	.049*	4.667
Rice cultivation area	-.014	.032	.195	.659	.986
On-Farm income	.048	.018	7.362	.007*	1.049
Off-Farm income	.015	.009	2.546	.111	1.015
Access to credit	.026	.018	2.001	.157	1.026
Agricultural extension contact	-.452	.293	2.369	.124	.637
Attitude towards SPI	.578	.269	4.632	.031*	1.561

It was observed from Table 4 that family labor availability, land ownership status, on-farm income, and attitude towards SPI made a significant contribution to the non-adoption of SPI. The -2 Log Likelihood ratio is 121.150, which is different from 0. The Chi-square value is 46.853, which is significant at 1% level of confidence. The Cox and Snell R2 value of 0.352 and the Nagelkerke value of 0.446 indicate a good explanatory power of the independent variables on the dependent variable. The analysis is well-fitted, as indicated by all these parameters.

3.3.2. Factors influencing partial adoption of SPI

The results of factors influencing partial adoption of SPI are shown in the following Table 5. The table shows that, out of 10 independent variables, four namely educational level, family labor availability, on-farm income, and off-farm income had a significant effect on the partial adoption of SPI.

Table 5. Parameter estimation results for the partial adoption group

Independent Variables	β	S.E.	Wald	Sig.	Exp(β)
Age	.080	.060	1.772	.183	1.083
Level of Education	.373	.159	5.545	.019*	1.452
Family labor availability	-1.939	.947	4.194	.041*	.144
Landownership status	1.464	.905	2.614	.106	4.322
Rice cultivation area	-.047	.036	1.669	.196	.954
On-Farm income	.044	.018	6.099	.014*	1.045
Off-Farm income	.020	.010	4.266	.039*	1.020
Access to credit	.016	.021	.585	.444	1.016
Agricultural extension contact	-.131	.307	.183	.669	.877
Attitude towards SPI	-.449	.282	2.537	.111	.638

4. DISCUSSION

In the context of SPI adoption, the farmers were divided into three groups. The majority of farmers were non-adopters, followed by partial adopters and full adopters. This adoption status was influenced by some of the farmers' selected characteristics. It was determined through multinomial logistic regression analysis that the relationship between family labor availability and non-adoption of SPI was negative and significant. The farm labor availability b-value was -1.711, indicating that as family labor availability increased by one unit, the non-adoption of SPI by farmers decreased by 1.711 units. Based on the findings, it can be concluded that farmers with more available family labor are less likely to adopt SPI for irrigation. This tendency may lead to decreased interest in using SPI. Therefore, extension agents should focus on increasing the adoption of SPI among farmers with higher family labor availability. Wordofa et al. (2021) also found that family labor availability was positively associated with the adoption of improved agricultural technology.

The results of the study indicated that land ownership status did, in fact, play a significant role, leading to the rejection of the null hypothesis. The study found that as land ownership status increased, farmers' non-adoption of SPI also increased by 1.540 units, suggesting that farmers who own more land may be more likely to belong to the non-adoption group. The results are consistent with findings from Kangogo et al. (2021), Sarker et al. (2021), and Ruzzante et al. (2021), who also observed a positive and significant relationship between land ownership status and the adoption of modern agricultural technologies by farmers.

It was determined through multinomial logistic regression that the connection between on-farm income and farmers' non-adoption of SPI was positive and significant. The b-value of on-farm income was 0.048, indicating that as on-farm income increased by one unit, the non-adoption of SPI by farmers increased by 0.048 units. Based on these findings, it can be inferred that farmers who have higher on-farm incomes are more likely to use SPI. This may be due to the fact that when farmers have more on-farm income, they can afford their own irrigation systems to ensure timely irrigation of their fields, as solar pumps are not always capable of providing adequate irrigation during cloudy weather. Wordofa et al. (2021) and Sarker et al. (2021) also reported a positive and significant contribution between the adoption of improved agricultural technology and on-farm income.

It was observed through the multinomial logistic regression that the contribution of farmers' attitude on the use of SPI was significant and positive. The b-value of attitude towards SPI was .578, meaning that as attitude towards SPI increased by one unit, farmers' adoption of SPI also increased by .578 units. The study suggests that if farmers had a more favorable attitude towards SPI, the non-adoption group would decrease. The reason for this is that a favorable attitude indicates the farmers' interest in using SPI.

The b-value of the education level indicates that an increase of one unit in farmers' education level resulted in an increase of .080 units in their partial adoption of SPI. Based on the findings, it can be concluded that if farmers were better educated, they would be

more likely to adopt SPI. This could be due to the fact that farmers with higher education levels are more knowledgeable about new technology, which enables them to switch from traditional irrigation systems to new ones. Rana et al. (2021) also discovered similar results, demonstrating that education was positively and significantly associated with the adoption of solar irrigation technology.

The study found that farmers' family labor availability had a significant contribution to the partial adoption of SPI. The study also observed that the direction between family labor availability and partial adoption of SPI was negative. The finding is consistent with Kabir and Rainis (2015), who reported that family size is an important factor influencing farmers' decisions to adopt climate-smart adaptation strategies such as IPM. The b-value of family labor availability was (-1.939), which indicates that an increase of one unit in farmers' family labor availability led to a decrease of 1.939 units in their adoption of SPI. Based on the findings, it can be concluded that if farmers had more family members involved in farming, the probability of using SPI would be lower. This could be due to the fact that when more family members are engaged in farming, more opinions are generated, and through discussion, the most suitable option is found, hence reducing the interest in using SPI.

The contribution of on-farm income to farmers' partial adoption of SPI was positive and significant. From the findings, it can be inferred that an increase in family income might improve the probability of using SPI, as farmers may be more encouraged to try new technologies besides traditional ones due to increased income security. This is consistent with the results of Wordofa et al. (2021) and Sarker et al. (2021), who also found a significantly positive relationship between on-farm income and the adoption of improved agricultural technology.

The study revealed that the farmers' off-farm income had a significant contribution to their partial adoption of SPI. Based on the findings, it can be concluded that an increase in farmers' off-farm income would lead to an increased probability of using SPI. Additionally, the farmers' off-farm income may alleviate their fear of trying new technology besides the traditional ones. In a similar study, Sunny et al. (2023) also found a positive and significant relationship between off-farm income and the adoption of solar irrigation facilities.

5. CONCLUSION

Solar-powered irrigation (SPI) utilizes renewable energy from sunlight to generate power for irrigating various crops, particularly rice. The study revealed that the majority of rice growers did not adopt SPI despite expressing interest in adopting the technology. Only about 28% of the surveyed farmers adopted SPI, and among them, more than half were partial adopters, indicating the limited coverage of SPI. Initiatives should be undertaken by both public and private organizations to expand the establishment of SPI systems, enabling non-adopter farmers to adopt the technology and encouraging partial adopters to transition into full adopters. Furthermore, the government should provide support to the Bangladesh Agricultural Development Corporation (BADC) to facilitate the wider installation of SPI units across the country. In addition, support, motivation, and incentives should be provided to private sector actors to establish more SPI systems, thereby facilitating irrigation in rice fields. The present study only focused on the adoption status of SPI and the determinants that influence the decision to adopt SPI. Therefore, a further study should be conducted to assess the impact of using SPI on rice yield and profitability.

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Author Contributions

The first author designed the study and developed the first draft. The second author and third author thoroughly edit the draft and finalized.

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Conflict of interest

The authors declare that they have no conflicts of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Ethical approval

The study was approved by the ethics committee of Sher-e-Bangla Agricultural University Research System (SAURES). The study was done in conformity with ethical guidelines. Participation was entirely voluntary, and all respondents provided informed consent. The participants' anonymity and confidentiality were ensured, and the data obtained were utilized purely for the study. The ethical guidelines for Human Subjects are followed in the study.

Informed consent

Written & Oral informed consent was obtained from individual participants included in the study.

Data availability

All data associated with this study will be available based on the reasonable request to corresponding author.

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