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EVALUATION OF THE IMPACT OF SUSTAINABLE DEVELOPMENT GOAL INSTALLED SOLAR-POWERED PUMPS ON WATER ACCESSIBILITY AND SUSTAINABILITY IN SOME SELECTED AREA OF KEBBI STATE, NIGERIA

Shamsudeen Umar[1], Abdulhakim Abiola Akinlabi[2], Saidu Sunbo Akanji[3], Jamilu Mohammed Zuru[4]

[1,2,3,4]Department Of Electrical Engineering, Kebbi State Polytechnic Dakingari. Nigeria.

E-Mail: saiduakanji@gmail.com

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ABSTRACT

This study evaluated the impact of Sustainable Development Goal-installed solar-powered water pumps on water accessibility and sustainability across four Local Government Areas in Kebbi State, Nigeria. A cross-sectional survey design was employed, involving 1,200 respondents comprising household users, farmers, technicians and community leaders selected through stratified random sampling from Birnin Kebbi, Bunza, Kalgo and Suru Local Government Area. Data were collected using structured questionnaires and analyzed with SPSS version 27, employing descriptive statistics, chi-square tests and Pearson correlation. Results revealed significant geographic disparities in pump performance, with chi-square analysis demonstrating highly significant location effects ($\chi^2 = 290.535$, df = 9, $p < .001$). Birnin Kebbi exhibited high failure rates, accounting for 94.7% of all "very poor" ratings, while 27.1% of pumps across all locations were completely non-functional. Technical reliability analysis revealed moderate fault frequencies (mean = 2.95, SD = 0.77), with battery failures (40.3%) and motor problems (27.8%) predominating. Critically, 48.5% of faults either remained unresolved or required over three months for repair and a significant negative correlation existed between fault frequency and repair time ($r = -.468$, $p < .001$). Water adequacy assessment showed that 46.5% of users found supply insufficient, though agricultural impacts were positive with 59.8% reporting major or very significant contributions to farming activities. Despite operational challenges, 80.5% of respondents expressed confidence in solar pump sustainability as a long-term solution. The study concludes that while solar-powered pumps demonstrate potential for enhancing water accessibility and agricultural productivity in rural Nigeria, systematic implementation failures, inadequate maintenance infrastructure and location-specific contextual factors severely compromise performance outcomes. Recommendations include urgent investigation of Birnin Kebbi-specific failure factors, establishment of robust maintenance support systems with trained technicians and spare parts availability, comprehensive pre-installation site assessments incorporating hydrogeological and demand analyses, community capacity building for operation and management, quality assurance protocols for installation contractors and development of public-private partnerships to ensure sustainable long-term technical and financial support for solar water infrastructure investments.

Keywords: Solar-Powered Water Pumps, Pump Performance, Fault Frequency And Repair Time.

1. INTRODUCTION

In the developing countries, lack of clean water is a major developmental challenge and also one of the major obstacles towards achieving sustainable growth. Access to clean drinking water is a key factor in the SE4ALL initiative put forward in 2015 (WHO , 2022). This target is being pursued by policy makers in remote/rural areas and areas with little to no grid access in northern Nigeria through single intervention strategy, pumping water from the ground and storing it in a tank or directly feeding it to the masses. This type of system comprises three major components, the pump, the tank and the well. In systems that supply water directly to the masses, the need for tank is eliminated, but in such systems, one has to use a very powerful tank and/or provide a secondary means of powering the pump when the primary source of power is not available (Oyedokun et al., 2017). Thus, adding cost to the system and making it more complex. A better approach is to use an over-head tank for storing the pumped water and then supply it to the masses when needed using the potential energy of the water (gravity).

Another thing that differentiates water pumping systems is the type of energy source used in powering the pump. This energy source can be the utility grid, diesel/petrol generators, battery or some energy storage device and the solar panel. The utility grid as it is, is unreliable and inadequate, and therefore is not a good option (Bello-Yusuf & Bello 2020). Diesel generators despite their cost, are damaging to the environment. Batteries on the other hand cannot be used independently as they need to be recharged time and time again. Solar panels are proven to be the most economical, reliable (when coupled with batteries) and are environmentally sustainable.

Human development and well-being cannot be achieved without water quality and safety. Access to clean water is an effective instrument in promoting health and reducing poverty. In a document published by WHO, 15% of the global patients die in hospitals due to lack of proper hygiene as a result of limited supply of water (WHO, 2022).

In northern Nigeria, rainy season is the only farming season in most rural areas due to lack of water for irrigation, and farming is the major source of income in those areas (Sanchi, 2021). Immediately after the rainy season most of the people travel to other part of the country in search of employment, leaving behind only the women, children and the disabled (Sanchi, 2021). This is a major contributor to the high rate of poverty in the state relative other states in the north-central and southern parts of the country (Bello &Bello-Yusuf 2021). Ensuring the adequate and reliable and sustainable supply of water in remote areas will promote irrigation farming which in turn will reduce the rate of poverty and unemployment and boost the economy.

1.1 Statement of the Problem

Kebbi State in northwestern Nigeria has high solar energy potential but suffers from low rainfall, limiting water availability for domestic use and irrigation. While solar-powered water pumps were installed by government and NGOs to address this, many of these systems are now non-functional or abandoned. Additionally, public water supply systems, built decades ago, have not been upgraded despite growing population demands. Solar-powered pumps remain a promising solution due to their affordability, reliability and sustainability. However, their failure is often due to poor maintenance, technical faults and lack of support. There is a pressing need to assess how well these systems are performing, how technically reliable they are and whether they meet local water needs. This research aims to provide a clearer understanding of these issues, enabling better planning, improved system design and sustainable implementation in future water access projects in Kebbi State and similar regions.

1.3 Objectives of the study

The main aim of this research work is to evaluate the impact of sustainable development goal installed solar-powered pumps on water accessibility and sustainability in some selected area of Kebbi State, Nigeria. However, this research work shall meet the following specified objectives:

1. To assess the performance of solar-powered water pumps using user feedback and operational records.
2. To evaluate the technical reliability of the solar-powered pumps based on reported faults, maintenance history and available support capacity.
3. To examine the suitability of the installed solar-powered pump system in meeting water demand using technical specifications and user responses.

2. LITERATURE REVIEW

Oyedokun et al., (2017) designed a simulation model of a solar-powered pump for irrigation using PVSYST. The research illustrated how the erratic electricity supply in Niger State can be substituted with the use of solar-powered pumps for irrigation purposes. The simulated pump shows 65.8% efficiency in the dry season. The results confirmed the feasibility of solar-powered pumping systems for irrigation purposes in Kaduna and Niger States. Sanchi (2021) reviewed the causes and effects of dry spells during the rainy season. Major concepts of dry spells, such as meteorology, hydrology and water economy were examined from the United States Geological Survey (USGS) perspective. The study showed that dry spells are among the leading causes of famine, hunger, social conflicts, migration and relocation. Several mitigation strategies were proposed, with solar water pumping identified as a viable solution to enhance food security. Using geospatial techniques, the paper assesses and mapped out solar energy potentials in Kebbi State, North-western Nigeria. Two parameters were used as input parameters, Solar radiation and Digital Elevation Model (DEM) of the area. The DEM was used to generate slope and slope aspect. The slope, slope aspect and solar radiation of the study area were reclassified and weighted using Analytical Hierarchy Process (AHP). The results revealed that about 1912 km² of the study area have moderate solar energy potential; 2383 km² have good solar energy potential while 12,325.48 km² have very good solar energy potential. The analysis also revealed that Arewa-Dandi Local Government Area has the highest mean solar radiation energy of 5.53 kWh/m²/day; Birnin Kebbi has 5.41 kWh/m²/day while Ngaski has the lowest mean solar radiation energy of 4.80 kWh/m²/day. The research highlighted the great solar potential in this region and proved that using solar-powered pumps in the region is a smart move (Isma'il, 2018). (Gado et al., 2019) showed that Kebbi state has enough solar potential, and that 1kWp solar system can power an average household in the state. Insulation data of photovoltaic system scaled to its summer equivalent was used to establish the relationship between solar energy and power output in Argungu, Kebbi state. The research highlighted that if the government is willing, solar powered systems can be a viable solution to the problem of water scarcity in rural/remote areas. (Bello-Yusuf & Bello, 2020) explored the challenges and opportunities of solar-powered street lights in the city of Sokoto, northwest Nigeria. A descriptive approach was used to establish the status of the installed solar-powered street lights in the city. The challenges were discussed under three headings: technical, social, and institutional. The research pointed out that the failure of previous solar-powered street lights can be largely attributed to lack of maintenance, given that the project was optimally designed. Even though the regulatory bodies are moving away from solar to highly polluting diesel generators, adoption of solar energy for street lighting was shown to be a more sustainable solution. In their research titled “Solar water pumping: Kenya and Nepal market acceleration”, the authors showed that solar water pumping is mature and financially attractive for off-grid irrigation, animal feeding, and community water supply. The research work looked into some of the projects installed in Kenya and assess the factors that will accelerate their adoption in the community. It was shown that the major challenges faced by solar water pumping can be greatly reduced through public-private partnership. This partnership will provide innovative financing models and improve technology access, thereby accelerating the adoption of solar water pumping in Kenya and other parts of Africa (Kunen et al., 2015).

3. RESEARCH METHODOLOGY

This study employs a cross-sectional survey design to evaluate the performance, technical reliability and sustainability of solar-powered water pumps across four Local Government Areas in Kebbi State, Nigeria: Birnin Kebbi (the state capital), Bunza, Kalgo and Suru. These locations were purposively selected to represent both urban and rural contexts within the state's Sudan Savannah ecological zone, characterized by distinct wet (April-October) and dry (November-March) seasons relevant to solar pump performance assessment. A total of 1,200 respondents were recruited using stratified random sampling, with equal allocation across the four LGAs (300 per location). Household users and farmers were selected through systematic random sampling from community-based sampling frames, while technicians and community leaders were purposively sampled due to their smaller, specialized populations. Data were collected using a structured questionnaire developed through literature review and expert consultation, comprising four sections aligned with research objectives. Section A captured respondent demographics, Section B assessed operational performance using 5-point Likert scales addressing operational frequency, overall performance ratings, water quantity satisfaction and seasonal variations, Section C examined technical reliability through fault frequency (1=Very Frequently to 5=Never), fault types (categorical), repair times (1=Not resolved to 5=Quickly resolved), and maintenance support availability (1=Very Poor to 5=Very Good) and Section D evaluated suitability and sustainability through water adequacy, accessibility impact, agricultural contributions and sustainability perceptions on 5-point Likert scales. The questionnaire was pre-tested with 30 respondents and translated into Hausa to ensure accessibility. Data were entered into SPSS version 26.0 and cleaned through rigorous checks for out-of-range values and logical inconsistencies, with missing data (approximately 4.4-4.5%) handled using pairwise deletion. Descriptive statistics included frequencies, percentages, means, standard deviations, medians, and modes, while inferential analyses employed chi-square tests for categorical variables, one-way ANOVA with eta squared effect sizes for comparing means across groups, Pearson correlation for examining relationships between fault frequency and repair times and crosstabulation for exploring categorical associations, with statistical significance set at $\alpha = 0.05$. Ethical clearance was obtained from the appropriate institutional review board, with confidentiality maintained through secure data storage and restricted access.

4. RESULT ANALYSIS

4.1 Sample Characteristics

Table1: Respondent Category

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Household;	588	49.0	49.0	49.0
	Farmer	272	22.7	22.7	71.7
	Technician	178	14.8	14.8	86.5
	Leader	162	13.5	13.5	100.0
	Total	1200	100.0	100.0	

A total of 1,200 respondents participated in this evaluation study of solar-powered water pumps across four Local Government Areas in Kebbi State, Nigeria. The sample comprised 588 household users (49.0%), 272 farmers (22.7%),

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178 technicians/maintenance personnel (14.8%), and 162 community leaders (13.5%). Respondents were equally distributed across the four study locations, with 300 participants each from Birnin Kebbi, Bunza, Kalgo, and Suru, representing 25.0% of the sample per location. This distribution ensured balanced geographical representation across the state. The predominance of household users reflects the primary domestic water supply function of these systems, while the substantial farmer representation (22.7%) acknowledges the agricultural potential of solar pump technology in this predominantly agrarian region.

Table 2: Local Government * Respondent Category Crosstabulation

			Respondent Category				
			Household;	Farmer	Technician	Leader	Total
Local Government	Brinin Kebbi	Count	156	67	44	33	300
		% within Local Government	52.0%	22.3%	14.7%	11.0%	100%
	Bunza	Count	109	73	48	70	300
		% within Local Government	36.3%	24.3%	16.0%	23.3%	100%
	Kalgo	Count	156	67	44	33	300
		% within Local Government	52.0%	22.3%	14.7%	11.0%	100%
	Suru	Count	167	65	42	26	300
		% within Local Government	55.7%	21.7%	14.0%	8.7%	100%
Total		Count	588	272	178	162	1200
		% within Local Government	49.0%	22.7%	14.8%	13.5%	100%

The cross-tabulation of location by respondent category revealed notable variations in stakeholder composition across the LGAs. Bunza had the highest proportion of community leaders (23.3%), suggesting stronger community governance structures or greater local leadership engagement with the solar pump projects. Conversely, Suru had the lowest proportion of leaders (8.7%) but the highest percentage of household users (55.7%), indicating that the technology in this LGA may be more oriented toward domestic water provision than agricultural or community-wide applications. These compositional differences provide important context for interpreting performance and sustainability perceptions across locations.

4.2 Performance Assessment of Solar-Powered Water Pumps

Table 3: Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	290.535[a]	9	.000
Likelihood Ratio	277.700	9	.000
Linear-by-Linear Association	75.262	1	.000
N of Valid Cases	1146		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 22.39.

The analysis of operational performance across the four locations revealed significant and concerning patterns. When respondents were asked to rate the overall performance of solar pumps on a 5-point scale (1=Very Poor to 5=Very Good), substantial geographic disparities emerged. A chi-square test of independence demonstrated highly significant

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differences in performance ratings across locations ($\chi^2 = 290.54$, df = 9, $p < .001$), indicating that location substantially influences pump performance outcomes.

Table 4: Overall pump performance rating * Local Government Crosstabulation

			Local Government				
			Brinin Kebbi	Bunza	Kalgo	Suru	
Overall pump performance rating	Very Poor	Count	89	3	0	2	94
		% within Overall pump performance rating	94.7%	3.2%	0.0%	2.1%	100.0%
	Poor	Count	123	104	109	115	451
		% within Overall pump performance rating	27.3%	23.1%	24.2%	25.5%	100.0%
	Fair	Count	7	54	40	27	128
		% within Overall pump performance rating	5.5%	42.2%	31.3%	21.1%	100.0%
	Good	Count	80	127	137	129	473
		% within Overall pump performance rating	16.9%	26.8%	29.0%	27.3%	100.0%
Total		Count	299	288	286	273	1146
		% within Overall pump performance rating	26.1%	25.1%	25.0%	23.8%	100.0%

The distribution of ratings was particularly striking in Birnin Kebbi, where 94.7% of "Very Poor" ratings were concentrated, representing 89 out of 94 total very poor ratings across all locations. This overwhelming clustering suggests systemic performance failures specific to Birnin Kebbi's installations.

In Birnin Kebbi, performance ratings were predominantly negative, with 41.1% of respondents rating performance as poor and 29.8% as very poor, totaling 70.9% of respondents expressing dissatisfaction. Only 26.8% rated performance as good, with no respondents selecting "very good." This pattern contrasts sharply with the other locations. Bunza demonstrated a more balanced distribution, with the largest proportion of respondents (44.4%) rating performance as fair, followed by 36.1% rating it as poor and 44.1% rating it as good. Kalgo and Suru showed similar patterns, with the majority of ratings falling in the "good" category (47.9% and 47.3% respectively), though substantial proportions still rated performance as poor (38.1% and 42.1% respectively)

Table 5: Season pump performs best

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Dry season (November - March)	359	29.9	31.3	31.3
	Rainy season (April - October)	208	17.3	18.1	49.4
	Performance is consistent year-round	269	22.4	23.5	72.9
	Pump is non-functional in all seasons	311	25.9	27.1	100.0
	Total	1147	95.6	100.0	
Missing	System	53	4.4		
Total		1200	100.0		

The seasonal performance patterns revealed critical operational vulnerabilities. Among the 1,147 valid responses, 31.3% of respondents reported that pumps performed best during the dry season (November-March), while only 18.1% indicated better performance during the rainy season (April-October). Notably, 23.5% reported consistent year-round performance, which represents the ideal scenario for reliable water supply. However, most concerning was the finding that 27.1% of respondents indicated pumps were non-functional in all seasons, essentially representing complete system failures. This substantial proportion of non-functional systems calls into question the overall viability of current implementation approaches and suggests that more than one-quarter of installed capacity may be effectively wasted. The predominance of dry season performance (31.3%) appears counterintuitive given that solar irradiance should theoretically provide consistent energy throughout the year in this region. This pattern may reflect issues with water table levels, increased demand during dry periods exceeding system capacity or reduced maintenance attention during agricultural off-seasons. The 27.1% complete failure rate is particularly alarming and suggests fundamental problems with installation quality, system design, or post-installation support that render more than a quarter of the investments non-functional regardless of season.

4.3 Technical Reliability and Maintenance Challenges

The assessment of technical reliability revealed moderate fault frequencies but serious challenges in resolution capacity. The mean fault frequency score was 2.95 (SD = 0.77) on a scale where 1 represents "Very Frequently (Weekly)" and 5 represents "Never," indicating that faults occur occasionally to frequently across the study area. The distribution showed that 57.7% of respondents reported faults occurring occasionally (every 3-6 months), 21.6% rarely (once a year), 15.0% frequently (monthly), and 5.7% very frequently (weekly). While the majority experience faults only occasionally, the combined 20.7% experiencing frequent to very frequent faults represents a significant reliability concern affecting approximately one-fifth of installations. The analysis of fault types revealed that battery and storage system issues constituted the most common problem, reported by 40.3% of respondents, followed closely by pump motor failures (27.8%) and electrical wiring problems (27.5%). Pipe and tank leakage was relatively rare (2.7%), as was solar panel damage or theft (1.7%). The predominance of battery-related issues is particularly significant because battery replacement represents a substantial ongoing cost that many rural communities struggle to afford. The high frequency of motor failures (27.8%) suggests either poor quality equipment, inadequate load matching, or operational stresses exceeding design specifications. The relatively low incidence of theft (1.7%) is encouraging and may reflect effective community ownership or security measures, though this varies by location and installation context.

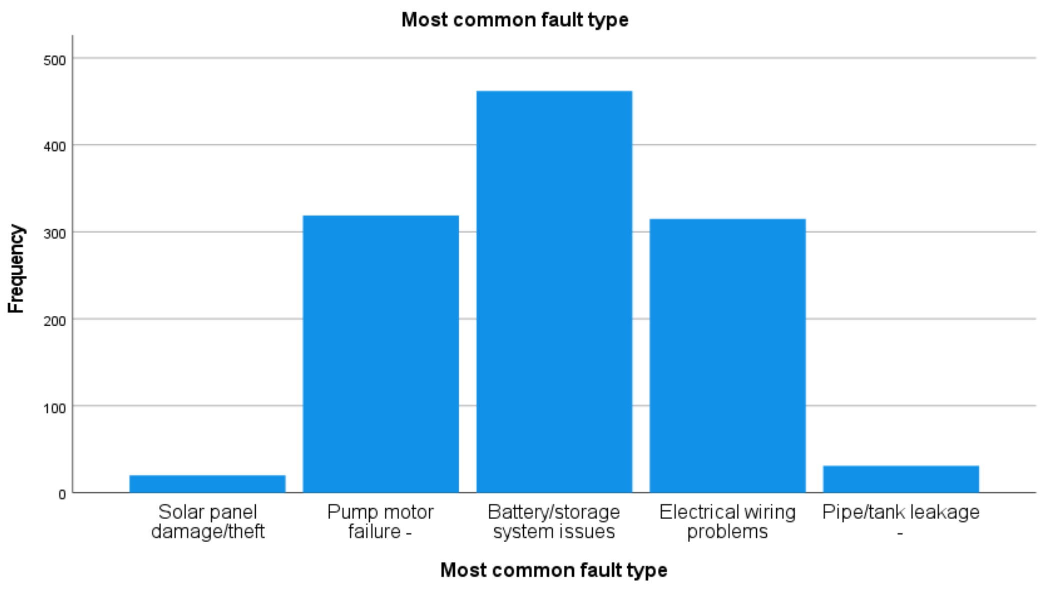

Figure 1: Frequency of occurrence of most common fault type

The repair and resolution time data exposed critical weaknesses in maintenance response systems. The mean repair time score was 3.11 (SD = 1.47), where higher scores indicate faster resolution. However, the distribution reveals troubling patterns. A substantial 14.4% of faults were never resolved, leaving pumps permanently non-functional. An additional 34.1% of faults took more than three months to resolve, and 3.5% took one to three months. Only 22.5% were resolved moderately (within 1-4 weeks), and 25.5% quickly (within one week). This means that nearly half of all faults (48.5%) either remain unresolved or take more than three months to fix, effectively rendering systems unreliable for extended periods.

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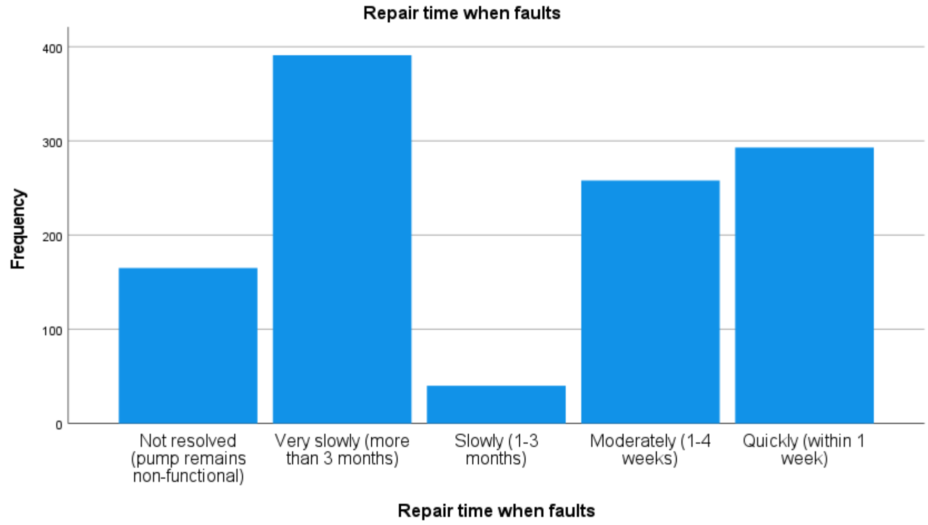

Figure 2: Time taken to resolve faults when they occur

Table 6: Correlations Analysis between Fault and Repair Time			
		Frequency of faults	Repair time when faults
Frequency of faults	Pearson Correlation	1	-.468**
	Sig. (2-tailed)		.000
	N	1147	1147
Repair time when faults	Pearson Correlation	-.468**	1
	Sig. (2-tailed)	.000	
	N	1147	1147

**. Correlation is significant at the 0.01 level (2-tailed).

The correlation analysis between fault frequency and repair time in table 6 above, revealed a significant negative relationship ($r = -.468$, $p < .001$, $N = 1{,}147$). This moderate negative correlation indicates that systems experiencing more frequent faults also tend to have slower resolution times. This relationship suggests a vicious cycle where inadequate maintenance capacity leads to both more frequent breakdowns and longer repair periods, progressively degrading system reliability. Communities experiencing frequent faults may face compounding challenges of parts depletion, technician unavailability or resource exhaustion that further delay repairs.

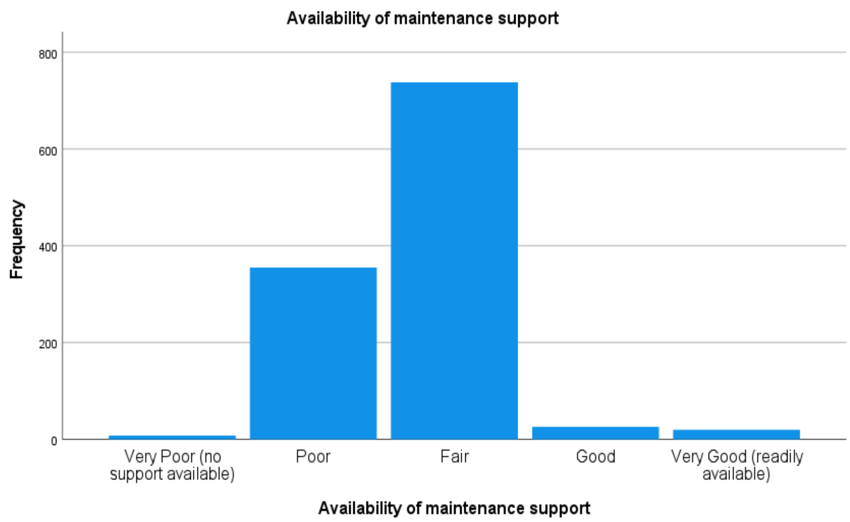

Figure 3: Availability of Maintenance Support

The assessment of maintenance support availability in figure 3 painted a concerning picture of inadequate technical infrastructure. Overall, maintenance support was rated at only 2.73 (SD = 0.60) on a 5-point scale, falling below the midpoint and indicating generally poor support. The distribution showed that 64.3% of respondents rated support as fair, 31.0% as poor, and only 0.7% as very poor, with minimal proportions rating it as good (2.3%) or very good (1.7%). The concentration of ratings at "fair" suggests that while some support exists, it falls far short of the "good" or "very good" levels needed for sustainable operations.

4.4 Suitability for Water Demand and Community Impact

The assessment of water adequacy for primary use in figure 4 revealed that solar pumps provide sufficient water for less than half of users. The mean adequacy score was 2.97 (SD not reported) on a scale from 1 (Completely Insufficient) to 5 (More than Sufficient), falling just below the "Barely Sufficient" threshold. The distribution showed that 4.3% found water completely insufficient, 42.2% insufficient, 7.8% barely sufficient, 43.7% sufficient, and only 2.1% more than sufficient. The combined proportion finding water insufficient or completely insufficient (46.5%) nearly equals those finding it sufficient or more than sufficient (45.8%), indicating a system that meets needs for less than half the user population. Only 2.1% reported more than sufficient supply, suggesting that systems are generally sized at or below demand levels with minimal safety margins. This pattern suggests that while solar pump technology can provide adequate water for some users, current implementations fail to meet needs for nearly half the population. The low proportion reporting "more than sufficient" supply (2.1%) indicates that oversizing to accommodate growth or peak demands is virtually non-existent. This may reflect cost constraints, conservative system design, or inadequate needs assessment during installation. The 7.8% finding supply "barely sufficient" represents a vulnerable group likely to experience periodic shortages during peak demand or system degradation.

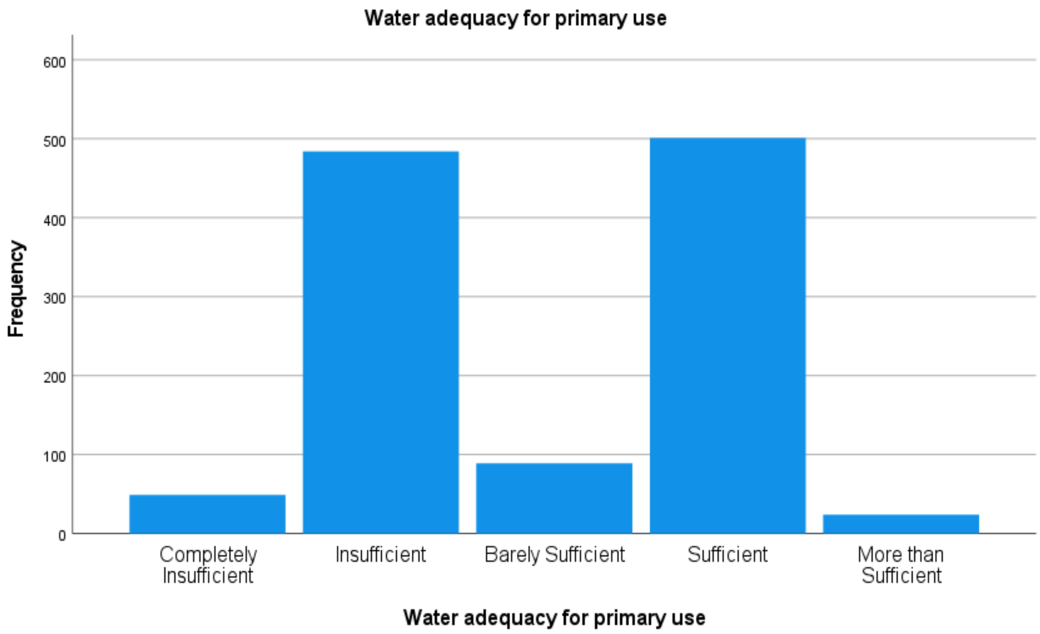

Figure 4: Assessment of water adequacy for primary use

The impact on water accessibility compared to pre-installation conditions showed mixed results. The mean impact score was 3.25 (median = 3.00, mode = 3), where 3 represents "No Change" on a scale from 1 (Significantly Worsened) to 5 (Significantly Improved). The distribution revealed that 53.5% reported no change in water accessibility, 19.6% reported worsening, 0.2% significantly worsened, 8.6% improved, and 18.0% significantly improved. These findings indicate that for the majority of respondents (53.5%), solar pump installation has not changed their water access situation. This neutral outcome may reflect that pumps replaced existing water sources of similar capacity, that performance problems negated potential improvements, or that pre-existing water access was already adequate. More troubling is that approximately one-fifth of respondents (19.8% combined worsened and significantly worsened) report that water accessibility actually deteriorated following solar pump installation. This counterintuitive finding suggests that in some cases, solar pumps may have replaced more reliable traditional sources, experienced rapid failures after installation, or raised expectations that went unmet. The 26.6% reporting improvements (combined improved and significantly improved) represents a modest success rate, indicating that roughly one in four installations delivers meaningful access improvements.

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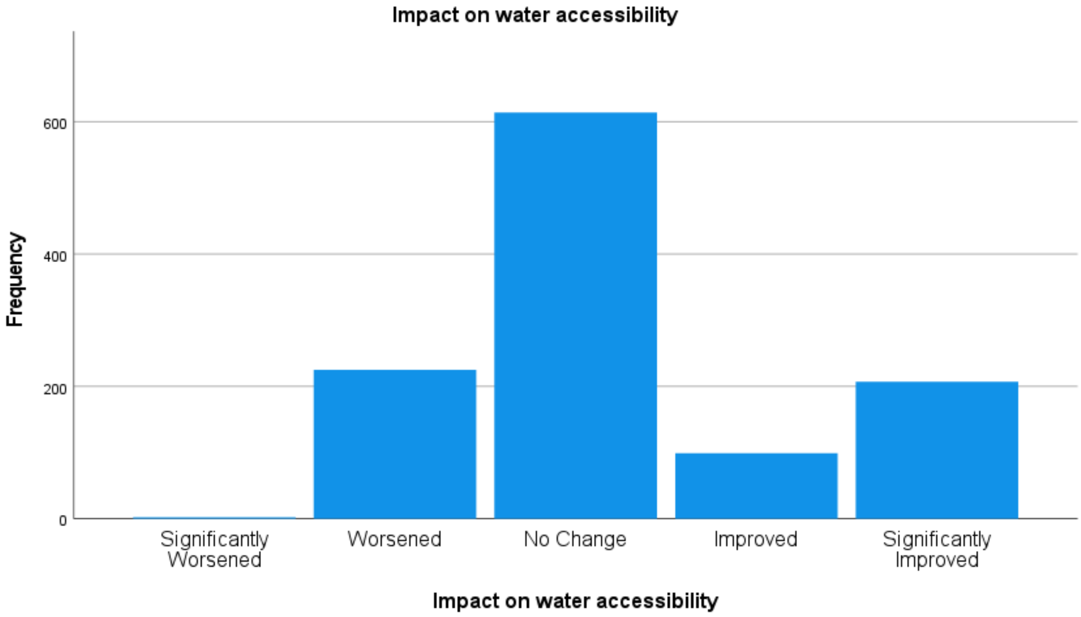

Figure 5: Impact on water accessibility

The agricultural impact assessment revealed more positive outcomes, though with notable variation. The mean agricultural contribution score was 3.68 (median = 4.00, mode = 4), indicating "Major contribution" as the most common response. The distribution showed that only 0.1% reported no contribution, 20.0% minor contribution, 20.0% moderate contribution, 31.8% major contribution, and 28.0% very significant contribution. The combined proportion reporting major or very significant contributions (59.8%) suggests that where solar pumps function properly, they substantially enhance agricultural productivity. This finding is encouraging and aligns with policy objectives of promoting irrigation farming in Kebbi State. The modal response of "Major contribution" (31.8%) and the concentration of ratings at the upper end of the scale indicate that solar pumps, when operational, effectively support irrigation activities. The relatively low proportion reporting no or minor contribution (20.1% combined) may represent non-farming households, locations with inadequate water flow for irrigation, or failed systems. The substantial proportion (28.0%) reporting "very significant contribution" suggests transformative impacts for some farming communities, possibly enabling dry-season farming, crop diversification or expanded cultivated areas.

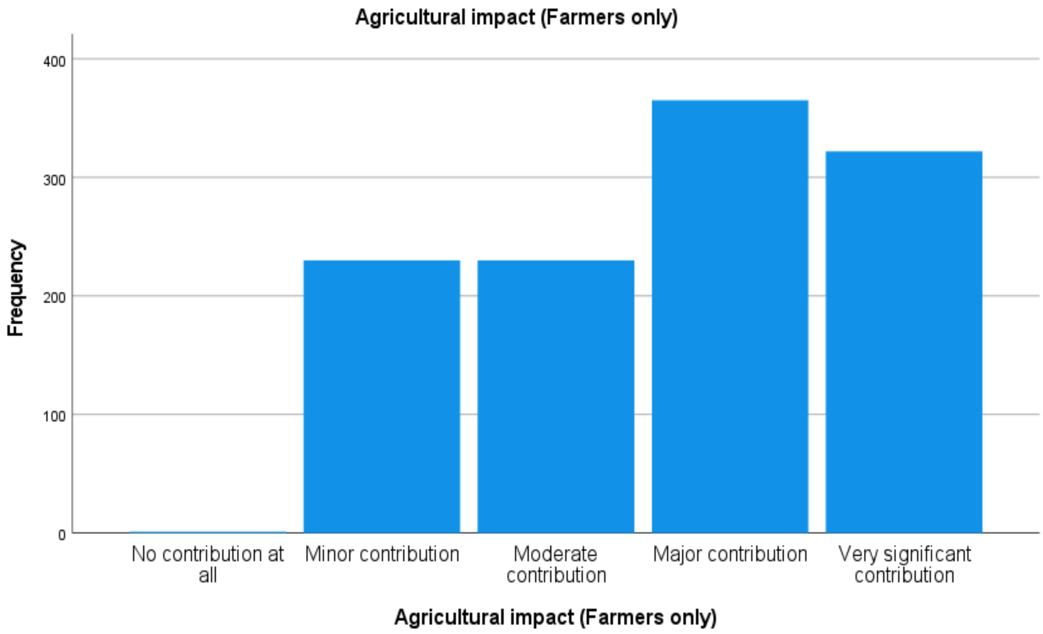

Figure 6: Agricultural Impact of Solar Pump

The sustainability perception data revealed surprisingly positive attitudes despite documented performance and maintenance challenges. The mean sustainability score was 4.21 (median = 5.00, mode = 5), with the mode at the

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maximum value indicating "Strongly Agree" that solar pumps represent a sustainable long-term solution. The distribution showed that 16.4% disagreed with sustainability, 3.0% were neutral or uncertain, 24.1% agreed, and 56.4% strongly agreed. The combined agreement proportion (80.5%) represents strong confidence in the technology's long-term viability despite evidence of significant operational challenges. This apparent contradiction between actual performance problems and high sustainability confidence may reflect several factors. Communities may value the concept of solar technology and its independence from fuel costs even when current implementations are problematic. The absence of viable alternatives may lead respondents to express optimism about solar solutions despite current shortcomings. Additionally, communities that have experienced even modest improvements may view solar pumps favorably relative to previous water access challenges. The sustainability perception may also reflect aspirational thinking about what the technology could achieve with proper implementation and support rather than satisfaction with current performance.

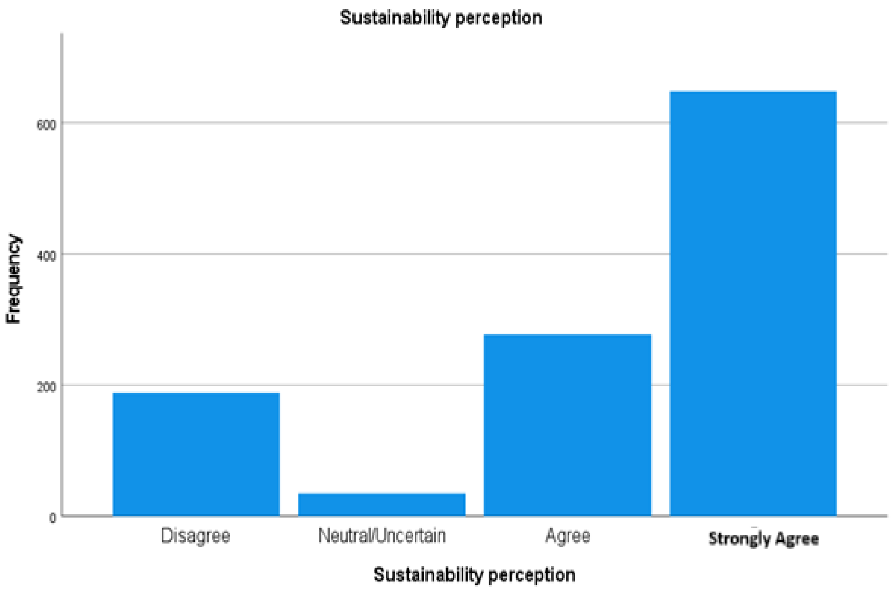

Figure 7: Sustainability Perception of Solar Pump

5. CONCLUSION

This comprehensive evaluation of solar-powered water pumps installed under Sustainable Development Goal initiatives in Kebbi State reveals a technology with substantial potential that is severely undermined by systematic implementation failures and inadequate support infrastructure. While the concept of solar-powered water provision aligns perfectly with the dual objectives of expanding water accessibility and promoting environmental sustainability in off-grid rural communities, the reality documented in this study presents a sobering picture of geographic performance disparities, technical reliability challenges and maintenance system inadequacies that threaten the viability of these investments. The high concentration of failures in Birnin Kebbi, where 94.7% of all very poor ratings originated and 70.9% of respondents expressed dissatisfaction, demands urgent investigation into location-specific factors distinguishing this area from better-performing locations. The finding that 27.1% of installed pumps are completely non-functional across all seasons represents an unacceptable waste of development resources and a profound failure to deliver on community expectations. The moderate fault frequencies combined with the critical finding that 48.5% of faults either remain unresolved or require over three months for repair reveals a maintenance infrastructure woefully inadequate for sustaining solar water systems. The significant negative correlation between fault frequency and repair time suggests a vicious cycle where inadequate support capacity leads to progressive system degradation. Despite these challenges, the finding that 59.8% of respondents report major or very significant agricultural contributions demonstrates that when solar pumps function properly, they deliver transformative benefits for irrigation farming and rural livelihoods. The paradox of high sustainability confidence (80.5% agreement) coexisting with documented performance problems suggests that communities recognize the technology's potential even while experiencing current implementation shortcomings. Based on these findings, this study recommends immediate remedial action in Birnin Kebbi through comprehensive technical audits and targeted interventions to address systematic failures. Program-wide improvements must include establishing robust maintenance support systems with trained technicians positioned in each Local Government Area, ensuring spare parts availability through strategic stockpiling or supply chain partnerships, implementing rigorous quality assurance protocols for installation

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contractors with performance-based accountability mechanisms, conducting comprehensive pre-installation assessments incorporating hydrogeological surveys and demand analyses to ensure appropriate system sizing and site suitability and developing structured community capacity building programs for pump operation, basic troubleshooting and management committee effectiveness. Future solar water infrastructure investments should adopt adaptive implementation frameworks that account for local contextual variations rather than standardized approaches, establish public-private partnerships to provide sustainable technical and financial support beyond initial installation and integrate post-installation monitoring systems to enable early detection of performance problems and rapid response interventions. Only through such comprehensive reforms can solar-powered water pumps fulfill their promise of delivering reliable, sustainable water access that transforms rural livelihoods and advances development objectives in Kebbi State and similar contexts across Nigeria and Sub-Saharan Africa.

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