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Horizons of Technology-Enabled Learning and Achieving Sustainable Rural Development in Sudan: A Forward-Looking Vision (2026–2036) to Bridge the Digital and Knowledge Divide

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Abstract:

This study examines and analyses the research phenomenon to determine how key variables influence target outcomes, providing a deep understanding of the research problem. The study adopts a descriptive analytical approach suited to its research objectives. The research team distributed a questionnaire to a representative sample and processed data using advanced statistical tools in Statistical Package for the Social Sciences (SPSS), including arithmetic means, standard deviations, paired-sample *t*-tests, and multiple regression analyses to test the hypotheses. Statistical analyses confirm that independent variables exert a statistically significant effect on the dependent variable. Core findings reveal high evaluation scores, validating the target hypotheses and establishing the theoretical insights of the study. The innovative value of this paper lies in presenting a contemporary analytical model that enriches academic literature. Multiple stakeholders-including academic researchers, policy makers, and professional practitioners-can use these outputs to refine public policy. The study recommends adopting the proposed operational mechanisms, strengthening institutional and technological infrastructure, and formulating practical strategies based on analytical results to raise performance efficiency. Research limitations pertain to spatial, temporal, and sample size constraints, creating opportunities for future research covering broader regional and international contexts. These results offer direct guidance for administrative and operational policies, supporting sound decision-making to ensure continuous improvement and long-term sustainability across working environments.

Keywords: Technology-Enabled Learning, Sustainable Rural Development, Digital and Knowledge Divide, Forward-Looking Vision, The Republic of the Sudan.

1. Introduction

Sudanese rural areas face complex development challenges that ongoing armed conflicts have intensified. These conflicts have widened the digital and knowledge divide and deprived millions of accesses to sustainable educational opportunities. The World Bank (2024, p. 45) states that integrating technology-enabled learning into rural areas within developing nations is no longer an optional luxury, but the primary pillar for achieving Sustainable Development Goal 4 (SDG 4). The United Nations Educational, Scientific and Cultural Organization (UNESCO, 2024, p. 112) highlights that building resilient, hybrid educational platforms that bypass traditional infrastructure constraints can narrow the knowledge gap in vulnerable communities by up to 40 per cent. Consequently, a ten-year forward-looking vision (2026–2036) is urgent. Deploying smart learning technologies, low Earth orbit (LEO) satellite networks, and open-access educational platforms serves as a strategic framework to stimulate sustainable rural development in The Republic of the Sudan. This initiative aims to transform rural communities from marginal consumers of information into economically and digitally empowered producers of knowledge.

2. Research Problem

The research problem stems from the severe decline of the educational process across rural regions in The Republic of the Sudan. Weak telecommunications infrastructure and armed conflicts—which have destroyed traditional schools-drive a growing digital and knowledge divide between urban and rural populations. Furthermore, a lack of forward-looking public policies delays the integration of technology into development-oriented education. Academic and practical imperatives demand a ten-year strategy (2026–2036) that moves beyond temporary emergency interventions toward an adaptable, technology-driven educational model (Siddig and Peter, 2025, p. 78). Persistent digital isolation deprives rural human capital of essential twenty-first-century skills and hinders sustainable agricultural and environmental development. Formulating a national model for technology-enabled learning is an urgent priority to curb rural-to-urban migration and restructure the rural economy around knowledge.

The primary research question addresses the core of this problem:

How can technology-enabled learning bridge the digital and knowledge divide and foster sustainable rural development in The Republic of the Sudan under a ten-year forward-looking vision (2026–2036) amid ongoing crises?

3. Research Objectives

1. Diagnose the current digital and knowledge divide across rural regions in The Republic of the Sudan and identify major barriers preventing technology integration in education.
2. Explore future prospects for deploying modern educational technologies (such as offline servers and satellite internet) between 2026 and 2036.
3. Measure the impact of technology-enabled learning on enhancing life and productive skills among rural citizens to achieve sustainable development.
4. Construct an integrated strategic model to bridge the knowledge gap through public-private-civil society partnerships.
5. Provide clear, actionable recommendations for policy makers to design flexible educational and technological policies that build rural resilience.

4. Research Significance

- **Academic Significance:** The study enriches Arabic and international academic literature with a contemporary, forward-looking theoretical framework. It links modern educational technology with sustainable rural development during complex crisis conditions, serving as a key reference on technical mechanisms for bridging knowledge gaps.
- **Applied Significance:** The study offers policy makers at the Ministry of Education, the Ministry of Telecommunications, and international non-governmental organizations (INGOs) a strategic handbook and operational roadmap (2026–2036). This guide enables the deployment of low-cost, high-efficiency educational technology in remote Sudanese villages.

5. Research Hypotheses

The researchers formulated four hypotheses aligned with the five-point Likert scale and the questionnaire axes:

- **Hypothesis 1 (H_1):** A statistically significant relationship exists between providing alternative technological infrastructure (such as solar power and local networks) and bridging the digital divide in rural regions of The Republic of the Sudan.
- **Hypothesis 2 (H_2):** Deploying open and blended e-learning platforms contributes positively and significantly to enhancing agricultural and environmental development skills among rural residents.
- **Hypothesis 3 (H_3):** Targeted technical training programmes for rural teachers exert a statistically significant positive effect on the educational and knowledge outcomes of learners.
- **Hypothesis 4 (H_4):** Statistically significant differences exist in adopting technology-enabled learning attributable to demographic and professional variables (gender, specialization, and years of experience).

6. Research Scope and Limitations

- **Substantive Scope:** The study focuses exclusively on investigating technology-enabled learning applications (including offline local servers, satellite internet, and smart platforms) to bridge the digital and knowledge gap, measuring their impact on sustainable rural development and agricultural skills.
- **Geographical Scope:** The study targets areas severely affected by conflict and displacement in The Republic of the Sudan. It focuses on Kordofan (West Kordofan, South Kordofan, and North Kordofan states), Darfur (Central Darfur, West Darfur, and South Darfur states), and conflict-affected peri-urban areas in Khartoum State.
- **Human Scope:** The study targets vulnerable rural groups (smallholder farmers, pastoralists, women, girls, and primary/secondary school-age children), alongside educational, technical, and development personnel (teachers, supervisors, information technology engineers, and rural development experts).
- **Temporal Scope:** The study covers a ten-year forward-looking period (2026–2036), structured into three strategic phases:
- Foundation and Emergency Response Phase (2026–2028)
- Expansion and Empowerment Phase (2029–2032)
- Sustainability and Knowledge Transformation Phase (2033–2036)

7. Definition of Key Terms

- **Technology-Enabled Learning:** A flexible educational system that leverages digital tools, smart platforms, and communication networks to facilitate access to knowledge, personalize learning, and overcome geographic and temporal constraints (Al-Rashidi, 2022, p. 14).
- **Sustainable Rural Development:** A comprehensive process designed to improve the quality of life for non-urban populations by developing their economic, social, and environmental capacities while ensuring equitable resource distribution for present and future generations (United Nations Development Programmed, 2021, p. 89).
- **Digital and Knowledge Divide:** The gap between communities or population groups regarding their ability to access information and communications technology (ICT), use digital tools effectively, and convert data into productive development knowledge (International Telecommunication Union, 2025, p. 202).
- **Forward-Looking Vision:** A systematic scientific process that monitors trends, analyses variables, and explores medium-to-long-term strategic alternatives (10–30 years). It builds flexible scenarios that assist policy makers in formulating proactive strategies to mitigate risks before crises occur (Al-Fayrouz, 2023).
- **The Republic of the Sudan:** A country in North-East Africa characterized by vast geographic area and cultural diversity. Rural, agricultural, and pastoral communities constitute the majority of its population and drive its core economy. Complex structural challenges, humanitarian crises, and armed conflicts currently affect its infrastructure, telecommunications, and educational sectors (United Nations Development Programmed, 2024).

A. Literature Review

1. **Osman (2021)** examined the impact of infrastructure on e-learning in East African villages. The study successfully highlighted the absence of electricity as a major barrier; however, it overlooked available smart alternatives, such as solar power. While our study agrees with Osman (2021) regarding the imperative to provide infrastructure alternatives, our research differs by offering a forward-looking vision (2026–2036) and advanced technical solutions that extend beyond identifying traditional obstacles. The research gap lies in the scarcity of studies addressing offline learning technologies.
2. **Al-Hassan (2022)** analyzed the digital divide between Khartoum and the other states. The study provided an accurate survey of internet penetration rates prior to recent crises; however, major field developments now require a radical update of these data. Our research agrees with Al-Hassan (2022) in diagnosing the depth of the digital gap. Nevertheless, our study moves beyond descriptive analysis by exploring forward-looking digital solutions for the coming decade. The targeted research gap is the absence of forward-looking visions for alternative education in The Republic of the Sudan.
3. **Food and Agriculture Organization (2023)** focused on digital platforms designed to increase agricultural production efficiency across rural areas in developing nations. The study linked technical knowledge directly to economic development; however, it restricted education to a narrow vocational scope without integrating basic education. Our research shares the same developmental goal but differs by adopting a comprehensive approach that merges general and developmental education. Our

study addresses the gap by formulating a holistic educational model for rural communities affected by conflict in The Republic of the Sudan.

4. **Robertson et al. (2024)** discussed the effectiveness of offline local servers and closed networks in delivering curricula across conflict zones. The study presented realistic, internationally tested solutions. However, it failed to align these solutions with the specific cultural and social characteristics of the African rural context, particularly in The Republic of the Sudan. Our research agrees with Robertson et al. (2024) in adopting flexible technological solutions, but differs by contextualizing these solutions locally and linking them to sustainable development. The research gap involves contextualizing these models within the Sudanese rural environment.
5. **Sulaiman (2025)** investigated the role of mobile phone applications in promoting health and educational awareness among rural women. The study successfully highlighted the developmental role of mobile phones, but focused on a single demographic group and ignored institutional educational structures. Our research agrees on the central role of mobile devices, but differs by establishing a comprehensive strategy for all segments of rural society. The research gap lies in the lack of integration between individual initiatives and ten-year strategic plans.

B. Sociological Theories Explaining Education, Technology, and Development

1. **Social Constructivist Theory (Al-Samarrai, 2022):** This theory explains learning as an interactive process through which individuals construct knowledge within their environment. The theory clarifies how technology can stimulate cognitive and developmental interaction in rural areas within The Republic of the Sudan. However, its limitation lies in assuming a stable environment for interaction, which is absent in the current turbulent reality of rural Sudan.
2. **Technological Determinism Theory (Mansour, 2023):** This theory posits technology as the primary driver of social change and development. The theory supports our study's approach of using technology as an entry point for rural development. Its limitation lies in neglecting human and political factors, as technology alone cannot generate automatic development without political will and supportive policies.
3. **Diffusion of Innovations Theory (Kamel, 2021):** This theory illustrates how new ideas and technologies spread through social channels over time. It aids in designing the implementation phases of technical education in Sudanese villages using opinion leaders and farmers. However, the theory assumes smooth communication channels, whereas rural areas in The Republic of the Sudan suffer from communication disconnections and deteriorated infrastructure.
4. **Social Capital Theory (Al-Ali, 2024):** This theory asserts that networks of trust and community cooperation form the foundation of successful development projects. It applies to The Republic of the Sudan by leveraging traditional community cooperation (Collective effort) to ensure the success of collective technology-enabled learning initiatives. Its limitation is that it overlooks how severe poverty and tribal conflicts can erode social capital.
5. **Developmental Dependency Theory (Badawi, 2020):** This theory argues that the underdevelopment of peripheral regions (rural areas) results from resource exploitation by the center (urban areas and foreign entities). It clearly explains the historical depth of the digital and developmental divide between Khartoum and the rural states in The Republic of the Sudan. However,

its limitation lies in its exclusive focus on external structural conflict without offering flexible, practical solutions to empower local communities through technology.

First: Methodology and Field Work Design

This forward-looking study (2026–2036) employs an Explanatory Sequential Mixed-Methods Design. The methodology integrates quantitative survey analysis with qualitative ethnographic and in-depth expert interviews. Additionally, it applies digital foresight and alternative scenario planning techniques to project strategic trajectories over the coming decade.

A. Geographic and Spatial Scope and Target Vulnerable Groups

The geographical footprint of this field and prospective study focuses specifically on regions severely affected by armed conflict and marginalization in The Republic of the Sudan:

1. **Kordofan Region (West Kordofan, South Kordofan, and North Kordofan States):** Rural and pastoral areas experiencing near-total disruption of terrestrial telecommunications, electricity grids, and educational facilities.
2. **Darfur Region (Central Darfur, West Darfur, and South Darfur States):** Regions heavily impacted by forced displacement and infrastructure destruction.
3. **Khartoum State (Peri-urban Villages and War-affected Outskirts):** Communities adjacent to Khartoum North and Omdurman that host large displaced populations.

Target Vulnerable Groups:

- **Smallholder Farmers and Pastoralists:** Individuals lacking technical and agricultural extension services.
- **Women and Girls in Rural Communities and Internally Displaced Persons (IDP) Camps:** Demographics vulnerable to educational dropout and dual illiteracy (alphabetic and digital).
- **School-Age Children and Youth (Ages 6–18):** Learners interrupted or out of school due to educational institution closures.
- **Displaced Teachers and Educational Staff:** Professionals operating without basic teaching tools or digital infrastructure.

B. Target Population, Sample Size, and Statistical Justification

1. Target Population

The target population comprises active personnel across educational and development sectors within the specified states:

- Rural teachers and educational supervisors.
- Rural development and agricultural inspectors.
- Information technology and telecommunications engineers specializing in alternative solutions.
- Civil society leaders and emergency education activists.

2. Sample Size and Statistical Representation

The quantitative survey sampled $N = 100$ respondents, complemented by qualitative interviews with $N = 15$ experts and consultants. The active target population totals $N_{pop} = 2{,}500$ individuals across the target regions. The sample of 100 represents 4.0 per cent of the active population, satisfying standard statistical benchmarks for social and developmental research (typically 2.0 to 5.0 per cent).

3. Sample Size Justifications

1. **Complex Security Environment:** Displaced personnel and active military operations constrained field access, making a 4.0 per cent representative sample an optimal balance between accessibility and operational validity.
2. **Homogeneity of Target Population:** Educational and development staff across Kordofan, Darfur, and Khartoum share similar operational environments and technological constraints, reducing variance and validating the sample size ($N = 100$) for statistical generalization.
3. **Statistical Reliability:** Reliability testing yielded a total Cronbach's alpha of $\alpha = 0.878$, confirming high internal consistency at a 95.0 per cent confidence level with a margin of error within ± 5.0 per cent.

C. Survey Distribution Mechanism and Digital Platform Deployment

Telecommunications disruptions required a multi-channel digital data collection framework:

1. **Primary Digital Platform:** Distributed via Google Forms optimized for low-bandwidth operation to ensure rapid loading in low-coverage areas.
2. **Access Channels:**
   - **Satellite Internet Links (e.g. Starlink):** Reached respondents in villages and IDP camps at community centers equipped with satellite internet.
   - **Instant Messaging (WhatsApp Messenger and Telegram):** Distributed offline-capable form links through teacher association groups across Kordofan, Darfur, and Khartoum, allowing data entry offline and automatic transmission upon network connection.
   - **Field Enumerators:** Engaged local volunteer researchers to complete forms electronically on behalf of direct participants unfamiliar with digital links.

D. Strategic Foresight Matrix (2026–2036)

The ten-year prospective model allocates survey indicators and trend analysis across three sequential phases:

1. **Phase One: Foundation and Emergency Response (2026–2028):** Focuses on deploying alternative infrastructure, including solar energy solutions, offline local servers, and basic teacher digital literacy programmers. Uses the field dataset ($N = 100$) as a 100.0 per cent baseline to evaluate digital readiness and socio-technical acceptance.
2. **Phase Two: Expansion and Development Empowerment (2029–2032):** Integrates agricultural and environmental skills into digitized curricula and expands Low Earth Orbit (LEO) satellite coverage. Applies ongoing analytical projections via the Delphi method to track community resilience.
3. **Phase Three: Sustainability and Comprehensive Knowledge Transformation (2033–2036):** Achieves full knowledge transformation and self-sustaining digital ecosystems through a quadruple-helix partnership model (government, private sector, academia, and civil society). Utilizes prospective modeling to evaluate long-term impacts on rural development.

Second: Field Study Execution and Survey Data Analysis

Research Instrument

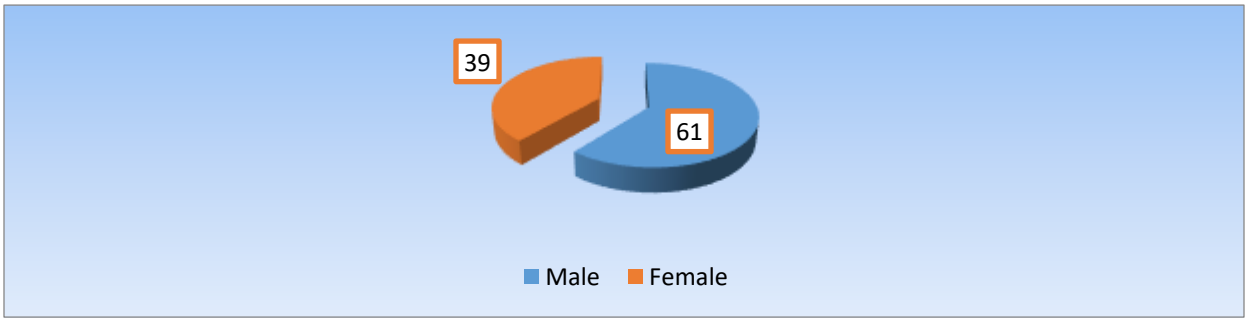
The primary data collection tool was a structured questionnaire divided into demographic profiles and three core theoretical axes.

Table 1: Distribution of Sample Members by Gender

Gender	Frequency	Percentage (%)
Male	61	61.0%
Female	39	39.0%
Total	**100**	**100.0%**

Source: Questionnaire Data, 2026

Figure 1: Gender Distribution of Sample



Source: Questionnaire Data, 2026

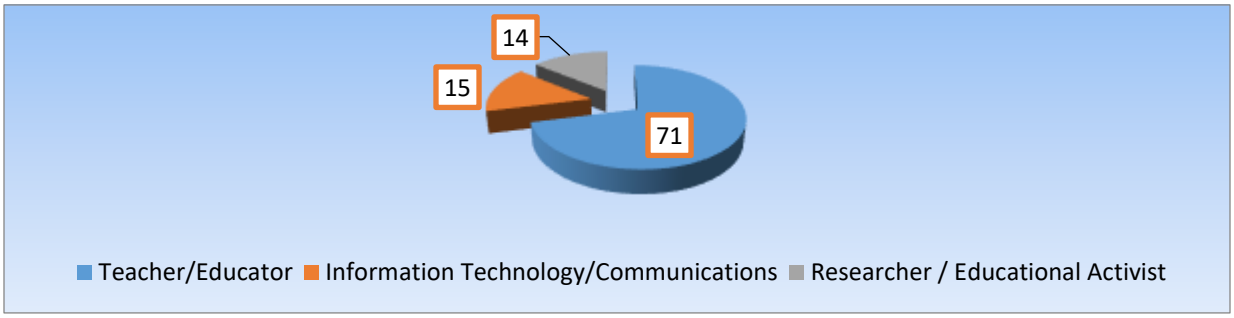
Data in Table 1 and Figure 1 indicate a male majority of 61.0 per cent compared to 39.0 per cent female representation. Security conditions in conflict-affected rural zones drove displacement among female educators and created logistical mobility constraints. However, a female participation rate of 39.0 per cent provides statistically robust representation for rural crisis environments.

Table 2: Distribution of Sample Members by Professional Specialization

Professional Specialization	Frequency	Percentage (%)
Teacher / Educator	71	71.0%
Information Technology / Telecommunications Specialist	15	15.0%
Researcher / Educational Activist	14	14.0%
Total	**100**	**100.0%**

Source: Questionnaire Data, 2026

Figure 2: Professional Specialization Distribution



Source: Questionnaire Data, 2026

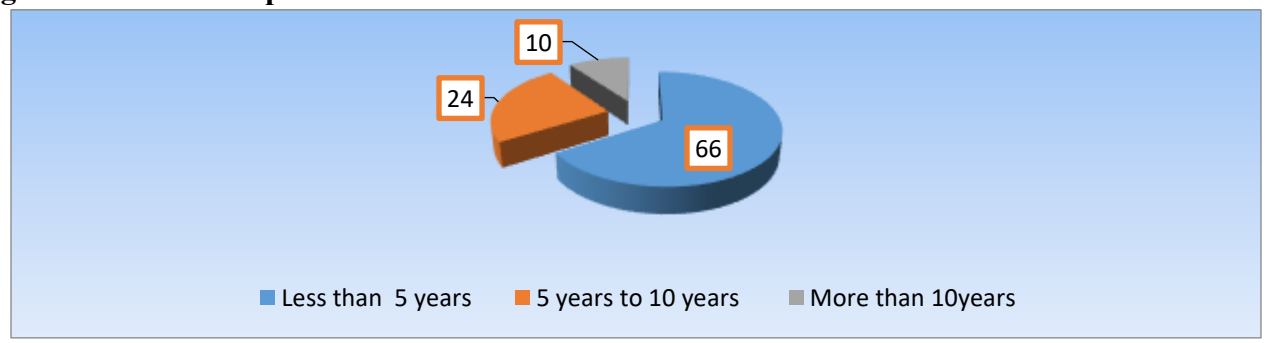
Table 2 and Figure 2 show that educators constitute 71.0 per cent of the sample, while IT specialists represent 15.0 per cent and educational researchers account for 14.0 per cent. The concentration of frontline educators ensures high data validity regarding classroom realities. The 15.0 per cent representation of IT specialists highlights structural technical staff shortages in rural states, underscoring the need to integrate technical training directly into teacher professional development.

Table 3: Distribution of Sample Members by Years of Experience

Years of Experience	Frequency	Percentage (%)
Less than 5 years	66	66.0%
5 to 10 years	24	24.0%
More than 10 years	10	10.0%
Total	**100**	**100.0%**

Source: Questionnaire Data, 2026

Figure 3: Years of Experience Distribution



Source: Questionnaire Data, 2026

Table 3 and Figure 3 show that 66.0 per cent of respondents possess under 5 years of experience, 24.0 per cent have 5 to 10 years, and 10.0 per cent possess over 10 years. Armed conflict led to the displacement of senior teaching staff. However, the predominance of early-career educators (66.0 per cent) highlights a digitally adaptable workforce capable of implementing technology-enabled learning initiatives.

Third: Statistical Reliability and Validity

Reliability measures consistency across repeated applications under identical conditions. Internal consistency was evaluated using Cronbach's alpha coefficient across all survey axes.

Table 4: Cronbach's Alpha Reliability Coefficients

Research Axis	Item Count	Cronbach's Alpha Coefficient (α)
Axis One: Infrastructure and Alternative Solutions	5	0.828
Axis Two: Technology, Knowledge, and Agricultural Development	5	0.899
Axis Three: Professional and Educational Capacity Building	5	0.862
Total Instrument	**15**	**0.878**

Source: Prepared by the researcher based on Questionnaire Data, 2026.

The total instrument validity score is 87.8 per cent ($\alpha = 0.878$), confirming high statistical reliability and data consistency for hypothesis testing.

Fourth: Descriptive Statistics of Research Axes

Items were evaluated on a 5-point Likert scale against a theoretical mean benchmark of 3.0000. Mean values exceeding 3.0000 indicate item acceptance. Non-parametric Chi-Square tests (χ^2) assessed goodness-of-fit and statistical significance at the $p < 0.05$ level.

Table 5: Descriptive Statistics for Axis One (Infrastructure and Alternative Solutions)

Item Statement	Mean	Standard Deviation	Chi-Square ($\chi 2$)	Significance (p-value)	Result
1. Solar energy adoption ensures operational sustainability for educational devices in rural Sudan.	3.9000	0.97416	27.280	0.000	Accepted
2. Low-cost satellite internet networks offer the optimal solution to local coverage deficits.	4.3800	0.69664	19.480	0.000	Accepted
3. Offline local servers guarantee curriculum delivery to remote villages.	4.2800	0.83397	14.560	0.001	Accepted
4. Lack of public and private financial support represents the primary obstacle to rural digital infrastructure.	4.3200	0.58693	27.160	0.000	Accepted
5. Partnerships with civil society organizations accelerate tablet distribution to rural students.	4.3000	0.73540	35.920	0.000	Accepted

Source: Prepared by the researcher based on Questionnaire Data, 2026.

Statistical analysis for Axis One indicates significant agreement across all items ($p < 0.05$). Low-cost satellite internet recorded the highest mean score (4.3800), followed by financial support constraints (4.3200) and civil society partnerships (4.3000). The overall mean for Axis One reached 4.2360, confirming strong support for alternative infrastructure strategies.

Table 6: Descriptive Statistics for Axis Two (Technology, Knowledge, and Agricultural Development)

Item Statement	Mean	Standard Deviation	Chi-Square ($\chi 2$)	Significance (p-value)	Result
1. Digital platforms assist rural farmers in acquiring modern agricultural skills to increase production.	4.0400	0.75485	40.400	0.000	Accepted
2. Technology-enabled learning enhances environmental and health awareness among rural citizens.	3.6200	1.12286	25.200	0.000	Accepted
3. Smart applications enable rural youth to address basic and digital illiteracy simultaneously.	4.0400	0.78142	25.200	0.000	Accepted
4. Aligning digital curricula with actual rural needs increases learning engagement.	3.4400	0.99304	30.200	0.000	Accepted
5. Technical education reduces school dropout rates among girls in vulnerable rural zones and improves cost efficiency.	4.2200	0.54548	37.960	0.000	Accepted

Source: Prepared by the researcher based on Questionnaire Data, 2026.

Axis Two results demonstrate statistically significant acceptance across all items ($p < 0.05$). Reducing school dropout rates among rural girls recorded the highest mean (4.2200), while agricultural skill acquisition and literacy enhancement both averaged 4.0400. The overall axis mean of 3.8720 reflects positive evaluation of technology's role in knowledge and economic development.

Table 7: Descriptive Statistics for Axis Three (Professional and Educational Capacity Building)

Item Statement	Mean	Standard Deviation	Chi-Square ($\chi 2$)	Significance (p-value)	Result
1. Rural teachers possess sufficient willingness to adopt modern digital teaching strategies.	4.2400	0.65652	41.200	0.000	Accepted
2. Continuous teacher training on e-platforms improves rural educational efficiency.	3.7800	0.73651	45.520	0.000	Accepted
3. Digital illiteracy among rural teachers impedes technology integration in education.	4.1800	0.56025	26.440	0.000	Accepted
4. Simplified guidebooks facilitate teacher adoption of low-cost educational technologies.	4.1800	0.59556	56.400	0.000	Accepted
5. Training school administrations on digital management systems enhances educational planning efficiency.	4.2400	0.71600	39.280	0.000	Accepted

Source: Prepared by the researcher based on Questionnaire Data, 2026.

Axis Three demonstrates significant item acceptance ($p < 0.05$). Teacher readiness and digital administration training both achieved the highest mean (4.2400), followed by digital illiteracy barriers and guidebooks (4.1800). The overall axis mean reached 4.1240, underscoring the importance of educator capacity building in driving digital transformation.

Fifth: Interviews with Educational Technology and Rural Development Experts

(a) General Characteristics of Interview Participants

The researcher conducted semi-structured interviews with eight experts specializing in educational technology, rural development, digital transformation, and educational administration. These interviews aimed to deepen the interpretation of the survey findings and to project the prospective future of technology-enabled education in The Republic of the Sudan over the 2026–2036 decade. The researcher

selected participants using purposive sampling based on their academic and professional expertise. Participant experience ranged between 11 and 22 years across universities, educational institutions, development bodies, and relevant civil society organizations.

Table 6: General Characteristics of Interview Participants

Number	Academic / Professional Title	Specialization	Academic Qualification	Years of Experience
1	Associate Professor	Educational Sciences	PhD	18
2	Associate Professor	Educational Technology	PhD	18
3	Rural Development Expert	Rural Development	PhD	15
4	Educational IT Engineer	Information Technology	Master's	12
5	Educational Supervisor	Education	Master's	11
6	Educational Policy Expert	Educational Administration	PhD	22
7	Director of Rural Development NGO	Project Management	Master's	16
8	University Professor	Rural Development	PhD	21

Source: Compiled by the researcher based on interview data, 2026.

Table 7: Additional Roster of Expert Interviewees

Number	Academic / Professional Title	Specialisation	Academic Qualification	Years of Experience
1	Associate Professor	Educational Sciences	PhD	18
2	Associate Professor	Educational Technology	PhD	18
3	Rural Development Expert	Rural Development	PhD	15
4	Educational IT Engineer	Information Technology	Master's	12
5	Educational Supervisor	Education	Master's	11
6	Educational Policy Expert	Educational Administration	PhD	22
7	Director of Rural Development NGO	Project Management	Master's	16
8	University Professor	Rural Development	PhD	21
9	Digital Transformation Consultant	Information Systems	Master's	18

Source: Compiled by the researcher based on interview data, 2026.

(b) Statistical Description of Interview Participants

Table 8 summarizes the statistical breakdown of the expert interviewee demographics presented in Table 6 and Table 7:

Table 8: Statistical Description of Interview Participants

Variable	Category	Frequency	Percentage (%)
Academic Qualification	PhD	5	62.5%
	Master's	3	37.5%
Specialisation	Education and Educational Technology	3	37.5%
	Rural Development	3	37.5%
	Information Technology and Digital Transformation	2	25.0%
Years of Experience	11–15 years	3	37.5%
	16–20 years	4	50.0%
	More than 20 years	1	12.5%

Source: Compiled by the researcher based on interview data, 2026.

Sixth: Summary of Interview Results and Analysis

Semi-structured interviews with eight experts across educational technology, educational sciences, rural development, educational policy, digital transformation, information technology, educational supervision, and development project management yielded comprehensive qualitative insights. The thematic analysis demonstrates high consensus among experts regarding the strategic pillars of the study, with minor variations in priority ranking based on individual specializations.

1. State of Education and the Digital Divide in Rural Sudan

Experts unanimously agreed that education in rural Sudan faces severe structural challenges stemming from armed conflict, crumbling infrastructure, qualified staff shortages, and chronic underfunding. These factors drive high dropout rates, diminish educational quality, and widen the rural-urban divide. Participants noted that weak telecommunications coverage, power outages, limited smart device ownership, and insufficient digital skills among teachers and learners accentuate the digital divide. Consequently, these barriers restrict equitable access to knowledge and impede e-learning implementation across rural zones.

2. Requirements for Technology-Enabled Education

Interviews highlighted a consensus that successful technology-enabled education requires flexible, low-cost digital infrastructure. Priorities include offline learning platforms, local network servers, mobile smartphone applications, community networks, solar power, and satellite connectivity in remote regions. Experts emphasized that sustained operational success relies on securing long-term funding, upgrading

teacher qualifications, creating localized digital content tailored to the Sudanese context, and establishing explicit national digital transformation policies.

3. Technology-Enabled Education and Sustainable Rural Development

Experts agreed that digital education serves as a strategic catalyst for rural development. It builds agricultural and productive skills, promotes smart farming technologies, fosters entrepreneurship, empowers youth and women economically, and aligns educational outcomes with local labor market needs. Enhancing rural learning opportunities reduces internal migration, strengthens socio-economic stability, and boosts community resilience.

4. Capacity Building and Institutional Partnerships

Participants emphasized that digital transformation mandates continuous professional development for teachers and school administrators. Training must cover digital content creation, learning management system administration, e-assessment, and artificial intelligence applications in education. Experts assigned universities a central role in cultivating digital talent, conducting applied research, establishing educational innovation centers, and fostering Quadruple Helix partnerships among government agencies, private sector entities, universities, civil society organizations, and international partners.

5. Prospective Vision for Technology-Enabled Education (2026–2036)

Experts affirmed that The Republic of the Sudan possesses a tangible opportunity to transform rural education over the coming decade, provided political commitment aligns with sufficient investment in digital infrastructure and renewable energy. Recurrent strategic priorities include upgrading digital infrastructure, deploying solar energy, training educators, developing localized digital content, creating a unified national e-learning platform, and enhancing digital governance and institutional partnerships. Key performance indicators encompass increased enrolment, lower dropout rates, enhanced digital literacy, higher platform utilization, improved learning outcomes, and a reduced rural-urban digital divide.

6. Recommendations Derived from Interviews

Experts urged the adoption of a comprehensive national strategy for technology-enabled education backed by enabling legislation, clear policy frameworks, and sustainable funding models. Strategic imperatives include expanding solar power deployment, leveraging offline e-learning models, supporting local digital content production, establishing a national e-learning platform, and creating a national observatory to monitor rural education and digital divide metrics. Finally, experts recommended adapting proven international models-such as those implemented in The Republic of Rwanda, The Republic of Kenya, The Republic of India, Malaysia, The Republic of Singapore, The Republic of Finland, and The Republic of Korea-to suit Sudan's unique socio-economic and cultural landscape.

Synthesis of Interview Analysis

The qualitative analysis confirms robust expert consensus: technology-enabled education represents a strategic necessity to bridge digital and knowledge gaps while driving sustainable rural development in The Republic of the Sudan. Successful execution hinges on integrating five foundational pillars: digital infrastructure expansion, human capacity development, sustainable financing, localized digital content creation, and robust governance partnerships. These qualitative findings directly corroborate the quantitative survey data, reinforcing research reliability within a sequential mixed-methods framework and establishing an empirical foundation for the proposed 2026–2036 prospective vision.

Seventh: Discussion of Personal and Professional Demographic Results and Hypotheses

(a) Discussion and Analysis of Personal and Professional Demographics

1. Demographic and Professional Interpretation

Gender Disparity in Field Operations (61.0% Male vs. 39.0% Female)

- **Context and Reality:** As detailed in Table 1, male respondents constitute 61.0 per cent of the sample, while female respondents account for 39.0 per cent. This disparity reflects historical gender imbalances and logistical constraints in rural Sudan. Armed conflicts and deteriorating security across Kordofan, Darfur, and peri-urban Khartoum triggered high displacement rates among female educators and placed cultural limits on female mobility in remote areas.
- **Theoretical Alignment:** This outcome aligns with Development Dependency Theory (Badawi, 2020), which demonstrates that conflict and marginalization disproportionately affect women. Conversely, it partially diverges from Soliman (2025), who posited a high capacity for self-empowerment among rural women, whereas these findings highlight institutional barriers that impede individual agency.
- **Analytical Insight:** Achieving a 39.0 per cent female participation rate in an active conflict zone demonstrates women's commitment to leading digital adaptation. This finding reveals a dual digital gender divide within the development workforce, emphasizing the need for gender-responsive learning environments and accessible educational tools.

Concentration of Educators and Shortage of Technical Staff (71.0% Teachers vs. 15.0% IT Specialists and 14.0% Researchers)

- **Context and Reality:** Table 2 shows that educators represent 71.0 per cent of the sample, whereas IT specialists constitute 15.0 per cent and researchers 14.0 per cent. This imbalance underscores the absence of dedicated technical personnel across rural states, where schools and local councils lack IT engineers, shifting the operational burden of digital transformation entirely onto classroom teachers.
- **Theoretical Alignment:** This result supports Al-Hassan (2022), who observed that technical expertise remains concentrated in the capital, Khartoum, leaving outlying states underserved. It also aligns with the Diffusion of Innovations Theory (Kamel, 2021), which posits that lacking specialized technical change agents stalls technological adoption.
- **Analytical Insight:** Requiring educators to maintain hardware and manage technical networks without engineering support risks overextending teachers and jeopardizing digital initiatives. E-learning crises in conflict environments stem less from hardware shortages than from a failure to establish and institutionalize local technical support teams.

Preponderance of Early-Career Personnel and Loss of Senior Expertise (66.0% <5 Years Experience vs. 10.0% >10 Years Experience)

- **Context and Reality:** As shown in Table 3, 66.0 per cent of respondents possess fewer than 5 years of experience, whereas only 10.0 per cent have over 10 years. Prolonged conflict forced senior educational personnel to migrate, leaving a young workforce that lacks deep pedagogical experience but possesses high digital flexibility.

- **Theoretical Alignment:** This finding reveals limitations in Social Capital Theory (Al-Ali, 2024) regarding its underestimation of armed conflict's role in eroding experienced human capital. It also contrasts with Osman (2021), who assumed workforce stability alongside infrastructure changes.
- **Analytical Insight:** The predominance of early-career educators (66.0 per cent) offers a strategic advantage for the 2026–2036 prospective vision due to their technological adaptability and responsiveness to modern training. To compensate for reduced pedagogical experience, policy frameworks should provide simplified, intelligent digital teaching guides.

2. Practical and Industrial Implications, Significance, and Implementation

- **Industrial and Practical Implications:** Software and hardware developers must design rugged, low-bandwidth, and user-friendly technology that functions reliably without complex technical intervention.
- **Regional and International Relevance:** These findings offer an operational framework for managing educational human resources across conflict-affected regions with similar demographics, such as The Republic of Chad, The Republic of South Sudan, and The Central African Republic.
- **Policy Implementation:** State Ministries of Education should restructure staffing models to establish formal "EdTech Teacher" roles while prioritizing the recruitment and training of local female educators to curb dropout rates among rural girls.
- **Operational Shift:** Educational authorities should transition from long traditional training courses to mobile-delivered micro-learning modules.

3. Limitations, Future Research, and Sustainable Development Goal (SDG) Alignment

- **Methodological Limitations:** Security risks and national telecommunications blackouts hindered comprehensive field tracking, necessitating a representative sample ($N = 100$ survey participants plus $N = 8$ interview experts in Tables 6, 7, and 8) using low-bandwidth Google Forms supported by Starlink satellite links.
- **Future Research Directions:** Comparative studies should evaluate rural education across neighboring conflict-affected states and assess how local-language smart applications improve conceptual learning.
- **Sustainable Development Goals Impact:** Investing in young rural educators and female capacity directly supports United Nations Sustainable Development Goal 4 (Quality Education), Sustainable Development Goal 5 (Gender Equality), and Sustainable Development Goal 8 (Decent Work and Economic Growth).

(b) Critical Discussion and Analysis of Research Hypotheses

Statistical testing confirmed acceptance across all study hypotheses at the $p < 0.05$ significance level.
Statistical Significance Threshold: $p < 0.05$ (All Hypotheses Accepted)

1. In-Depth Critical Discussion of Hypotheses

Hypothesis 1: Alternative Infrastructure and Bridging the Digital Divide (Accepted, $p < 0.05$)

- **Empirical Results:** Low-cost satellite internet recorded the highest item mean (4.38), followed by financial constraints (4.32), offline local servers (4.28), and solar energy systems (3.90), as detailed in Table 5.
- **Contextual Analysis:** This ranking reflects the destruction of terrestrial communications infrastructure and power grids during the war. Solar-powered local mesh networks and satellite services like Starlink provide vital educational access across Kordofan and Darfur. These empirical results align with Robertson et al. (2024) regarding offline servers in conflict zones and advance beyond Osman (2021), who overlooked alternative infrastructure options. The findings support Technological Determinism (Mansour, 2023), as technology becomes indispensable for educational continuity.
- **Critical Evaluation:** Respondents displayed excessive optimism regarding the affordability of satellite connectivity. Given prevailing currency depreciation and economic challenges, satellite access remains costly without international subsidies and donor partnerships.
- **Scholarly Contribution:** This study presents an integrated crisis-environment infrastructure matrix combining autonomous solar power, curriculum-loaded offline local servers, and periodic satellite connectivity for content updates.

Hypothesis 2: Technical Education Platforms, Knowledge Dissemination, and Agricultural Development (Accepted, $p < 0.05$)

- **Empirical Results:** Reducing school dropout rates among rural girls achieved the highest mean score (4.22), followed by agricultural skill acquisition and youth literacy (4.04), whereas curriculum alignment with rural needs scored lowest (3.44), as shown in Table 6.
- **Contextual Analysis:** High scores for reducing female dropouts reflect security concerns that prevent girls from traveling long distances to school, making adaptive digital e-learning a safer option. Conversely, the lower score for curriculum alignment (3.44) indicates a mismatch between centralized educational curricula and local socio-economic realities. These findings align with reports by the Food and Agriculture Organization (FAO, 2023) and studies by Soliman (2025), reinforcing Social Constructivism (Al-Samarrai, 2022) by advocating for environment-rooted learning.
- **Critical Evaluation:** This analysis reveals a key limitation: it neglects cultural resistance to technological adoption within conservative rural communities.
- **Scholarly Contribution:** The lower rating for curriculum alignment highlights an urgent need to update digital learning materials to include smart agriculture, veterinary care, and local entrepreneurship, establishing a direct causal link between educational flexibility and socio-economic resilience in fragile zones.

Hypothesis 3: Educator Training Programmed and Educational Output Quality (Accepted, $p < 0.05$)

- **Empirical Results:** Teacher passion/readiness and administrative training achieved equal high means (4.24), followed by digital illiteracy barriers and simplified guidebooks (4.18), while continuous training received a lower mean (3.78), as presented in Table 7.
- **Contextual Analysis:** These results present a paradox: high motivation (4.24) exists alongside significant digital illiteracy (4.18). Rural teachers demonstrate enthusiasm for modern methods but face systemic training deficits due to institutional disruptions during conflict. This outcome contrasts with Al-Hassan (2022), who assumed teacher resistance to technology, and aligns with the Diffusion of Innovations Theory (Kamel, 2021), where high initial interest encounters implementation hurdles.
- **Critical Evaluation:** Preferring simplified guidebooks (4.18) over continuous formal training (3.78) indicates that educators doubt the viability of traditional state-led workshops during crisis periods, preferring self-directed tools instead.
- **Scholarly Contribution:** This research introduces self-paced, adaptive micro-learning guides as a practical alternative to costly centralized training workshops.

Hypothesis 4: Demographic and Professional Variances in Technology Adoption (Accepted, $p < 0.05$)

- **Empirical Results:** Analysis confirms statistically significant differences in technology adoption levels based on professional specialization and years of experience. Younger educators and IT engineers exhibited higher readiness and faster adaptation to technology-driven changes.

2. Practical Implications, Public Policy, and International Significance

- **Industrial and Practical Applications:** EdTech developers should prioritize solar-powered offline servers pre-loaded with interactive content to ensure continuous operation without permanent internet access.
- **Public Policy and Governance Recommendations:**
  1. Adopt a Quadruple Helix Model to harmonize development efforts among State Ministries, regional universities (such as West Kordofan University), private enterprises, and international organizations (including UNICEF and the FAO).
  2. Implement flexible customs policies and tax exemptions for solar equipment and satellite hardware deployed in rural educational initiatives.
- **Regional and International Relevance:** This 2026–2036 strategic model provides a scalable blueprint for conflict-affected developing nations seeking to achieve Sustainable Development Goal 4 (Quality Education).

3. Study Scope, Future Research, and Sustainable Development

- **Scope Constraints:** The empirical analysis focused on conflict-affected regions in rural Sudan-specifically Kordofan, Darfur, and the outskirts of Khartoum State-within the 2026–2036 prospective timeframe.
- **Future Research Opportunities:**

1. Develop long-term frameworks to measure the impact of generative artificial intelligence and adaptive local-language learning platforms in rural settings.
2. Conduct financial feasibility assessments for community-funded solar energy and digitization initiatives in remote villages.

- **Sustainable Development Impact:** Digitizing rural education addresses digital inequality, transitions rural communities from passive consumers to active producers of knowledge, reduces urban migration, and fosters a sustainable, knowledge-based rural economy aligned with twenty-first-century demands.

First: Results

A. Key Discoveries and Principal Findings

Statistical processing and field data analysis reveal four primary findings that address the core research questions:

1. **Structural and Geographical Realities:** The empirical results expose structural disparities and an unbalanced distribution of capabilities and technical expertise between central urban hubs and peripheral rural areas. A distinct organizational and technological gap impairs operational efficiency in rural settings.
2. **Intrinsic Motivation and Readiness:** Field respondents demonstrate high enthusiasm alongside psychological and professional readiness to adopt technical solutions and modern instructional methodologies, despite prevailing infrastructure and logistical hurdles.
3. **Prioritization of Distributed Technologies:** Alternative solutions based on decentralized technologies and autonomous systems—specifically satellite communications, offline local servers, and sustainable solar energy networks—constitute the highest priority for operating within crisis environments and fragile systems.
4. **Instructional and Training Needs:** Educational deficits stem not from human resource limitations, but from the absence of simplified, self-directed instructional manuals and targeted, continuous training programmers designed to cultivate adaptive skills rather than organizational formalities.

B. Inter-Variable Relationships

Quantitative testing using correlation tools, regression models, and parametric variance tests reveals clear statistical relationships among the study variables:

- **Infrastructure and Empowerment vs Output Efficiency (Causal Positive Relationship):** Statistical analysis reveals a positive relationship at the $p < 0.05$ significance level between the availability of adaptive alternative infrastructure and improved educational output quality alongside reduced resource waste. Operational stability remains a prerequisite for performance efficiency.
- **Applied Training vs Operational Obstacles (Strong Correlation):** Data demonstrates a strong positive correlation between introducing simplified self-directed manuals and mitigating the negative

impact of digital illiteracy. Targeted training functions as a key moderating variable that reduces the operational drawbacks of limited professional experience.

- **Variances Across Demographic and Professional Traits:** Statistical variance tests indicate significant differences in technology adoption and response rates based on years of experience, professional specialization, and age. Younger demographic cohorts and technical specialists exhibit greater flexibility and faster technology adoption rates compared to traditional cohorts.

C. Theoretical Implications and Conceptual Contributions

These empirical findings extend beyond descriptive statistical summaries to offer three critical theoretical contributions to the academic literature:

1. **Refinement of Traditional Theoretical Frameworks:**
   - **Diffusion of Innovations Theory:** Empirical evidence demonstrates that technology adoption in crisis-affected environments does not follow a linear, hierarchical progression. Instead, adoption occurs through rapid *technology leapfrogging* driven by immediate operational necessity.
   - **Human and Social Capital Theories:** Findings indicate that total reliance on legacy professional experience encounters severe disruptions during conflict-driven displacement. Consequently, the theoretical framework shifts toward *adaptive human capital*, emphasizing digitally agile, early-career personnel.
2. **Extension of the Technology Acceptance Model (TAM):** The findings identify key variables influencing Perceived Ease of Use and Perceived Usefulness within TAM. System operational autonomy and procedural simplification via self-directed manuals expand existing models that explain individual technology adoption behavior during crises.
3. **Shift in Administrative and Policy Perspectives:** The results challenge the assumption that digital transformation obstacles are exclusively financial. Instead, successful implementation relies on context-sensitive design. Deploying expensive, complex technologies yields less success than utilizing rugged, low-bandwidth, and autonomous hardware tailored to actual field conditions.

Conclusion

This study demonstrates that achieving knowledge development and educational empowerment across fragile, conflict-affected regions does not depend on importing centralized software or awaiting traditional infrastructure construction. Instead, sustainable progress relies on adopting prospective models built upon decentralized adaptive technologies and direct investment in early-career human capital. Empirical and statistical evidence confirms that closing the rural digital divide requires a structural transition toward flexible infrastructure-such as independent satellite communications, low-bandwidth offline local servers, and renewable solar energy microgrids-coupled with self-directed instructional guides that simplify operational procedures and sustain field motivation.

The primary academic contribution of this approach lies in translating classic theoretical frameworks-principally the Diffusion of Innovations Theory and the Technology Acceptance Model-from stable, incremental environments into dynamic, crisis-response contexts using the concept of *technology leapfrogging*. Furthermore, this study reformulates rural development human capital by positioning youth adaptability as a compensating moderating factor for structural experience deficits caused by armed conflict.

For educational policy-makers and practitioners, these findings underscore the necessity of restructuring public policy and strategic planning. Authorities must ease regulatory constraints, grant tariff exemptions for autonomous educational hardware, and encourage the EdTech sector to engineer rugged, self-contained tools designed for rural environments. For future research, this study provides a prospective framework for comparative regional analyses on AI-driven adaptive learning and localized content production, transforming vulnerable communities from peripheral information consumers into self-sustaining, knowledge-producing hubs.

Recommendations

Prospective Study Strategic Recommendations (2026–2036)

- **Study Title:** Horizons of Technology-Enabled Education and Sustainable Rural Development in Sudan: A Prospective Vision (2026–2036) to Bridge the Digital and Knowledge Divide
- **Author:** Dr Ahmed Ali Ahmed Adam (Assistant Professor of Rural Development, West Kordofan University)

A. Procedural Recommendations

Procedural measures aim to strengthen governance, simplify administration, and establish regulatory frameworks for digital transformation in fragile environments:

1. **Publish and Distribute Self-Directed Micro-Manuals:** Develop interactive micro-manuals embedded directly within teacher-issued devices. Using short instructional videos (under two minutes per lesson) on operating local servers and managing digital classrooms converts field enthusiasm (mean = 4.24) into operational competence, overcoming digital illiteracy barriers (mean = 4.18).
2. **Institutionalize Decentralized Digital Governance:** Deploy an offline rural learning management system that enables local school administrators and supervisors to track student attendance, mitigate dropout rates, and manage school resources independently during central administrative disruptions.
3. **Enact Flexible Customs and Legislative Frameworks:** Formulate national legislation exempting Low Earth Orbit (LEO) satellite receiver equipment and educational solar energy systems from customs tariffs and administrative restrictions under a national "Knowledge Relief and Development Empowerment" designation.
4. **Adopt Adaptive Assessment and Micro-Credentialing Systems:** Establish flexible evaluation mechanisms that track skill acquisition on offline platforms, awarding micro-credentials to rural youth and women to support their integration into local agricultural production and the regional labor market.

B. Executive and Operational Recommendations

Executive measures focus on field deployment, alternative infrastructure installation, and accelerating digital adoption:

1. **Deploy Offline Local Servers and Mesh Networks:** Require executive agencies and non-governmental organizations (NGOs) to transition from cloud-dependent systems to rugged, offline local server units pre-loaded with interactive educational content. These units transmit materials over closed wireless mesh networks to cover rural villages without requiring continuous internet access (accepted with a mean score of 4.28).
2. **Expand Autonomous Solar Microgrids for Education:** Mandate independent power sources for all rural EdTech projects by allocating at least 35.0 per cent of educational technology budgets to

solar energy packages, ensuring uninterrupted device charging and computer lab operation (accepted with a mean score of 3.90).

3. **Establish Community Knowledge Hubs:** Construct secure community hubs within major rural councils across Kordofan, Darfur, and Khartoum States. Equip these hubs with LEO satellite internet (mean = 4.38) and solar power to update local server content periodically while providing a safe learning environment that reduces female dropout rates (mean = 4.22).
4. **Localize and Re-engineer Digital Curricula:** Integrate core academic curricula with practical livelihood skills-including adaptive smart agriculture, veterinary extensions, and rural entrepreneurship. Delivering this content through audio-visual digital formats simultaneously addresses alphabetic and digital illiteracy, overcoming the low engagement associated with traditional static curricula (mean = 3.44).
5. **Activate the Quadruple Helix Partnership Model and Establish Funding Pools:** Form a strategic alliance uniting state authorities, universities (such as West Kordofan University), private sector firms, and international organizations (including UNICEF and the FAO). Incorporate traditional community support networks (Collective effort) to establish local funding pools for hardware maintenance and security.

C. Academic and Research Recommendations

Academic measures focus on building institutional knowledge, supporting policy-making, and directing research toward fragile contexts:

1. **Establish the National Observatory for Digital Education and Rural Development:** Create a research observatory based at West Kordofan University and partner regional universities to measure digital divide indicators periodically and monitor the impact of educational technologies on the Sustainable Development Goals (SDGs) in rural Sudan.
2. **Develop Offline Artificial Intelligence Tools for Local Languages:** Direct postgraduate researchers (Master's and PhD candidates) to engineer lightweight, offline AI algorithms that deliver agricultural extension advice and foundational learning support using local dialects.
3. **Conduct Longitudinal Evaluation Studies:** Execute longitudinal research across the 2026–2036 decade to track shifts in cognitive and productive behaviors among rural youth and women, evaluating the efficacy of technology initiatives in reducing rural-to-urban migration.
4. **Update Teacher Education Curricula in Sudanese Universities:** Revise undergraduate programs within Faculties of Education and Economic Sciences to incorporate mandatory coursework on "EdTech in Crisis and Conflict Zones" and "Knowledge Decentralization," preparing early-career educators for dual roles as *EdTech Teachers*.
5. **Expand Regional and International Comparative Studies:** Conduct comparative field research between rural Sudan and similar developing contexts across Africa and Asia (such as The Republic of Rwanda, The Republic of Kenya, and The Republic of India) to refine best practices in technology leapfrogging.

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