Empowering Higher Education in Sudan Through Cloud Computing: Benefits, Challenges, and Opportunities Review paper

Ahmed Mohamed Alaagib Altegani[1] and Faroug Fadul Mater Konda[2]

[1]Department of Information Technology, Faculty of Computer Science and Information Technology, University of Sinnar, Sinnar-Sudan

[2]Department of Computer Science, Faculty of Computer Science and Information Technology, University of Sinnar, Sinnar- Sudan

Corresponding author email: ahmed-alaagib@uofs.edu.sd

ABSTRACT

The Higher Education (HE) infrastructure in Sudan has suffered considerably from ongoing armed conflict, creating a dire need for systems that ensure academic continuity. This paper presents a systematic review of Cloud Computing (CC) potential in modernizing Sudanese universities to mitigate the impacts of physical destruction and mass displacement. Utilizing the TOE (Technology-Organization-Environment) Framework, this study synthesizes research from 2014 onwards to evaluate the benefits, challenges, and strategic opportunities of cloud adoption in resource-constrained environments. Findings confirm that cloud migration offers transformative advantages, including shifting IT costs to operational expenditures and enhancing resilience through disaster recovery. However, unstable connectivity, power outages, and data sovereignty concerns remain critical barriers. The paper proposes pragmatic pathways, including Hybrid and Community Cloud models, to secure the future of Sudanese higher education.

Keywords: Cloud Computing, Higher Education, Sudan, Educational Resilience, Digital Transformation, E-learning, TOE Framework.

INTRODUCTION

Higher education is a pivotal pillar of the socio-economic recovery and future development of Sudan (Beshir *et al.,* 2020 and Sulieman, 2025). The country's universities have a key role in the

production of skilled graduates and driving innovation in research; they operate, however, amidst constant threat. This armed conflict tragically escalated these threats, where it caused the destruction of university buildings, the displacement of thousands of students and faculty, and the complete halt of on-premises operations (Alamin *et al.,* 2024 and Bashir, 2024). Capital-intensive, hard-to-maintain traditional on-premise IT infrastructure in HEIs in Sudan is also highly susceptible to physical and operation-related disruptions. Consequently, this is not just a modernization issue, rather than need for IT systems that are resilient, scalable, and affordable for the assurance of national academic survival and continuity. This paper addresses this gap by compiling cloud computing advantages, identifying adoption obstacles, and proposing a conceptual framework for implementation in the Sudanese sector.

The paper seeks to address this knowledge gap through a systematic critical review and synthesis of the academic literature concerning the use of cloud computing in Sudanese higher education. Thus, the review shall:

1. Compile the established advantages of cloud computing for academic and operational resilience in Sudanese higher education institutions.
2. Determine and categorize the main obstacles preventing cloud computing from being effectively adopted and used in the local context.
3. Draw attention to the strategic prospects and create a conceptual framework for implementing cloud computing to strengthen administrative resilience, teaching, and learning in Sudan's higher education sector.

Related Work

According to National Institute of Standards and Technology (NIST) Cloud Computing (CC) is defined as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Mell and Grance, 2011). CC is fundamentally changing how IT resources are consumed and managed globally. By leveraging service models, such as Software as a Service (SaaS), which provides learning management systems, Platform as a Service (PaaS) for research

environments, and Infrastructure as a Service (IaaS) for computing power, CC allows HEIs to shift from a Capital Expenditure to an Operational Expenditure model (Elgelany and Alghabban, 2017 and Adrees *et al.,* 2016; Ibrahim *et al*., 2021). This promises to deliver cost-efficiency, accessibility, and elasticity, which are crucial attributes for resource-constrained and conflict-affected environments like Sudan.

Whereas other developing regions have already enjoyed theoretical and practical successes from cloud migration, the adoption of CC in Sudanese HEIs has remained fragmented and slow (Karim and Rampersad, 2017). The existing literature has identified a critical tension between the pressing need for resilient, modern IT systems to sustain education against a backdrop of unstable technical, economic, and political environments-an unstable situation which has been heightened through war-while implementation is complicated by severe local constraining factors, including, but not limited to, inadequate and unstable Internet connectivity (Abubakar, 2016), a critical shortage of IT expertise, and ambiguous regulations related to data security and sovereignty. A synthesized understanding of specific local challenges, combined with immense potential, is important for informed decision-making that assures academic continuity during and after the conflict.

MATERIALS AND METHODS

Review Design and Approach

The study will take a systematic literature review approach in identifying, appraising, and synthesizing all available research findings related to the adoption of cloud computing in higher education institutions, focusing specially on Sudan and other similar developing countries within the African context. This will ensure transparency and reduce selection bias, thus reliably laying a foundation for evidence-based conclusions.

Search Strategy and Sources

A literature search was conducted from academic databases and repositories, such as: Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar. The search targeted direct studies on Sudan and contextual studies from economically and infrastructural similar regions. The search was conducted by using Boolean logic using the following key terms and their combinations:

Table 1. Key Terms of Search

Primary Keywords	Context Keywords	Focus Keywords
Cloud Computing	Sudan/ Sudanese	Benefits and Opportunities
Higher Education (HEIs)	North Africa	Challenges and Barriers
E-learning/ Digital Transformation	Sub-Saharan Africa	Implementation Models
Academic Continuity	Developing Countries	SWOT Analysis

Generally, the structure of the search string in each database was: (Cloud Computing or E-learning), (Higher Education or University), (Sudan or Africa) and (Challenges or Benefits).

Inclusion and Exclusion Criteria

Table 2 shows the strategy used as inclusion criteria to filter the retrieved studies, so as to ensure high degree of relevance and quality as well.

Data Extraction and Synthesis

Three stages of review followed to identify the literature, namely: title review, abstract reading, and full text assessment. Then, the relevant data extracted and categorized into three main themes that align to the objectives of the review: confirmed benefits, identified challenges, and strategic opportunities. The extracted data was then synthesized using a narrative synthesis approach that allowed for the critical evaluation of findings across different studies to identify consensus, contradictions, and gaps in the literature specific to the Sudanese HE context.

Proposed Conceptual Framework

Based on the systematic review and the synthesis of the Technological, Organizational, and Environmental (TOE) factors, this study proposes a conceptual framework (Figure 1) to guide the adoption of cloud computing in Sudanese HEIs. The framework illustrates how these three contexts act as drivers and barriers, influencing the selection of specific deployment models (SaaS,

Table 2. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Context	Studies explicitly discussing cloud computing in HEIs in Sudan or comparable African/developing nations with similar infrastructural and economic constraints.	Studies focused only on developed countries, primary education, or non-educational sectors.
Content	Empirical studies (case studies, surveys), theoretical papers, and other review articles that address the benefits, challenges, or opportunities of CC adoption.	Opinion pieces, non-peer-reviewed white papers, and technical papers focused only on cloud architecture without HE application.
Timeframe	Publications from 2014 to present, to capture the maturity and rapid development of modern cloud services. Exception: Foundational works for major theoretical models (e.g., NIST CC definition, DOI Theory, TOE Framework) are included regardless of date.	Publications dated before 2014, except for one source that presents the original definition of CC and core theoretical models.
Language	Articles published in the English language.	Articles not in the English language.

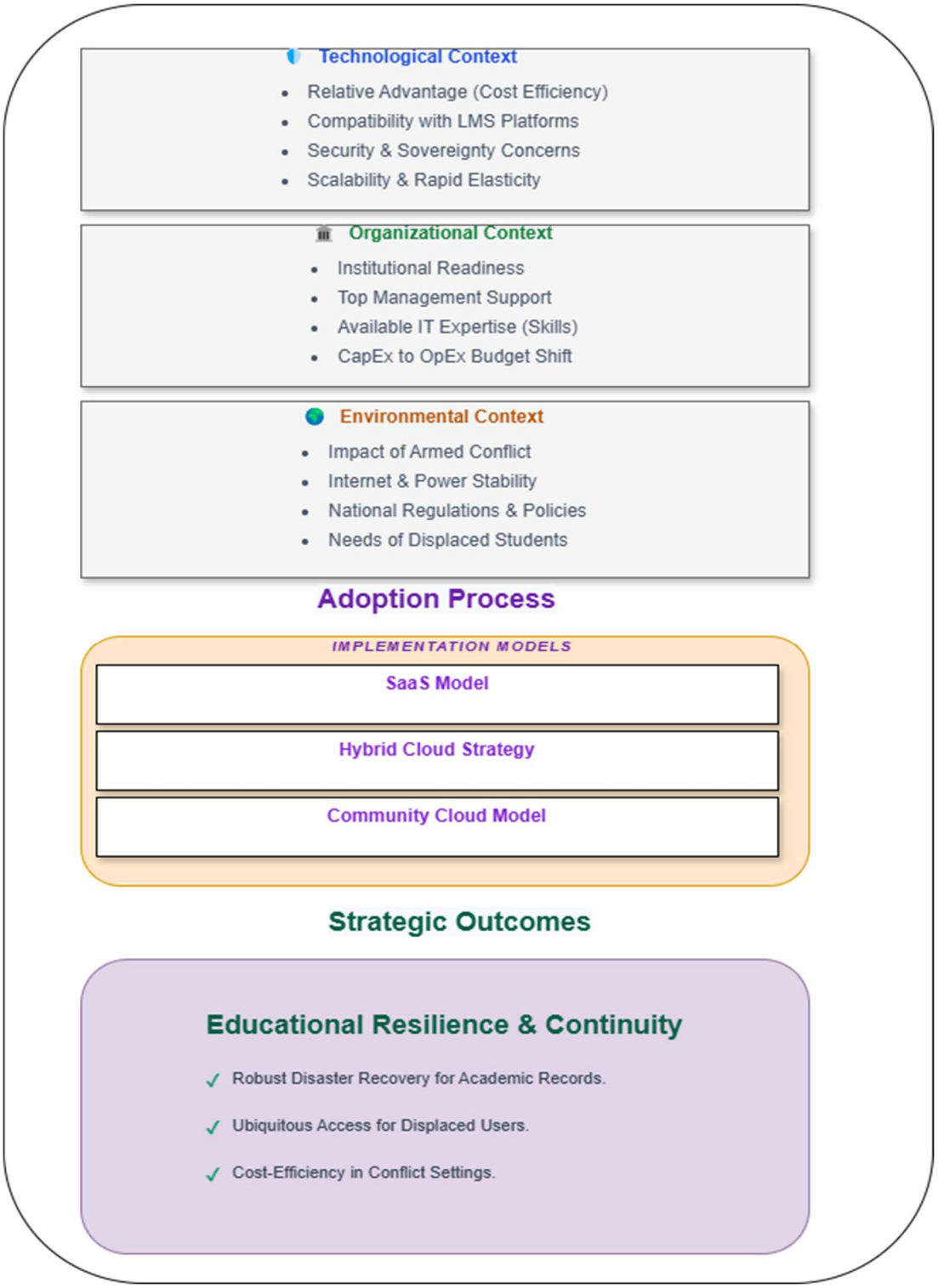

Figure 1. Conceptual Framework for Cloud Computing Adoption in Sudanese HEIs based on the TOE Model

Hybrid, and Community Cloud) to achieve academic continuity and educational resilience in the face of the ongoing conflict.

RESULTS AND DISCUSSION

The findings identified through the systematic review are categorized according to the dimensions of the proposed conceptual framework shown in Figure 1.

A. Identifies Benefits

Business Continuity and Operational Resilience

In a context that had been characterized by civil unrest, mass displacement, and physical infrastructural damage, the robust backup of data, disaster recovery, and geographic redundancy become paramount on the cloud (Tatineni, 2023). The CC allows HEIs to access core administrative services and learning resources when the university grounds are not accessible and/or have been destroyed (Baytiyeh, 2021). It keeps such vital systems as student records, financial information, and e-learning platforms running, hence serving as an academic survival strategy during the war (Al-Shaer *et al*., 2025).

Enhanced Accessibility and E-Learning Capacity

Cloud-based platforms provide ubiquitous access to educational resources, which support a geographically dispersed and displaced student body and facilitate remote learning (Okai-Ugbaje *et al.,* 2020). This directly facilitates supporting the students and staff displaced by conflict or residing in areas far away from any higher learning institution, so as responding to a vital social mandate of HE in Sudan through ensuring continuity in learning (UNICEF, 2023).

Cost Reduction and Economic Efficiency

The most quoted advantage is transitioning from Capital Expenditure-buying servers, software licenses, cooling systems-to Operational Expenditure-paying only for resources consumed. Researches into the adoption of CC in Sudanese HEIs always emphasize cost reduction as one of

the major strengths especially for these institutions whose budgets have been severely strained by war (Adrees et al., 2016). This economic efficiency enables the university budgets that are constrained to be shifted from IT maintenance to core academic activities such as faculty support or student scholarships.

Scalability and Resource Pooling

HEIs face fluctuating demands on computing resources, for example, during registration periods or for high-demand research projects. The rapid elasticity and resource pooling characteristics of CC enable universities to rapidly scale IT resources instantly up or down without owning excess capacity (Garcia-Perez, 2017). This immediately removes the need for expensive over-provisioned local data centers, freeing up high-performance computing resources for a wider array of faculty and researchers and also speeds up the reboot of academic activity after the conflict has ended at low cost.

B. Identified Challenges

Despite the obvious advantages, several significant context-specific challenges that could derail CC's successful adoption are identified in the literature.

Infrastructure Challenges (Environmental Context)

Internet Connectivity and Bandwidth

The major barriers identified in Sudan are poor quality, instability, and high costs of internet bandwidth; connectivity is particularly erratic and prone to disruption during the conflict (Giyane and Buckley, 2016). Most of the CC services depend on highly reliable and high-speed access; hence, even the basic SaaS model is challenging to use during failures or periods of low throughput (Abubakar, 2016).

Unreliable Power Supply: Due to frequent and very long power outages, local backup power systems (generators, UPS) are prohibitively expensive. Contradicting one of the key "no-infrastructure" selling points of cloud services, it increases operational costs (Garcia-Perez, 2017).

Technological Context Challenges (Security and Governance)

Data Security and Privacy: There is concern over the safety of sensitive institutional and student data hosted on remote servers managed by foreign entities (Mosweu *et al.,* 2019). The absence of a robust and particular national data sovereignty and protection framework in Sudan presents a huge legal and trust barrier, especially for those handling data pertaining to displaced persons (ALT Advisory, n.d.; Ilori, 2020 and Raji *et al.*, 2025).

Vendor Lock-in and Interoperability: Institutions are worried about dependence on a single cloud service provider that would make migration of data or services in the future quite difficult and expensive (Opara-Martins *et al.,* 2016 and Ayepola and Abos, 2024). This is a critical risk, as the long-term contracts that such a relationship often entails may turn out to be unsustainable or inflexible during periods of economic or political volatility.

Organizational Context Challenges (Skills and Policy)

There is an acute deficit of local IT expertise due to conflict-driven out-migration (Abubakar, 2016 and Qismallah, 2024). Besides, many HEIs lack a clear long-term strategic visions regarding cloud migration process (Isa *et al.,* 2019) or face internal resistance to changing legacy systems (Miyen and Marnewick, 2023).

The findings suggest that while challenges are formidable, they point to specific strategic opportunities for targeted intervention and successful cloud implementation suited to the Sudanese context of crisis and recovery.

A. Implementation Models

A pragmatic approach should prioritize SaaS and Hybrid models, first making use of the SaaS solutions - cloud-based email, collaborative tools, basic LMS (Chima *et al.,* 2025)-which involves very limited local infrastructure investment with immediate and observable benefits to be gained as per DOI theory (Rogers, 2003). Gradually, a Hybrid Cloud approach may be instituted where mission-critical or highly sensitive data is retained on a private cloud - on-premises or locally hosted - while public cloud can be used for high-volume and less sensitive applications (Elmasry

and Ibrahim, 2021). This balances out the security and cost aspects. In addition, a Community Cloud initiative led by the Ministry of Higher Education could allow institutions to share costs and maintain local data residency (Seke, 2015). The community cloud model enables many Sudanese HEIs to invest jointly in and share a common but possibly locally managed and operated cloud infrastructure and pool of expertise.

B. Strategic Partnerships and Policy

Universities should proactively partner with global providers (e.g., AWS, Azure) to access subsidized services and specialized training programs for faculty and students (MacCraith *et al.,* 2023). Such programs can effectively and directly address the critical skill gap.

Focusing on open source solutions helps to reduce fears of vendor lock-in and licensing costs, as cloud computing, using open-source management platforms and e-learning software. So, it is more compatible with open-source systems currently in use (Jeyaseelan, 2025). At the national level, a policy framework is required to adopting cloud computing in the HE sector (Kassim *et al.,* 2020). This strategy should address data sovereignty and set security standards for displaced students' data. Pilot projects, such as cloud-based registration systems, should be incentivized to demonstrate feasibility and reduce organizational resistance - Observability principle of DOI (Rogers, 2003).

CONCLUSION AND RECOMMENDATIONS

Cloud computing is a vital pathway for enhancing the resilience and cost-efficiency of Sudanese higher education amidst ongoing conflict. While infrastructural and human capital shortages are significant, a strategic national approach can overcome these barriers.

Future Directions

This review identifies the need for empirical primary research in order to quantify the adoption factors.

1. Cost-Benefit Analysis: Detailed economic case studies should be conducted to quantify the actual TCO difference between traditional IT and CC for typical Sudanese HEIs, including conflict-related damages and disruption costs.

2. User Acceptance: Empirical surveys on the level of acceptance and preparedness of faculty, students, and IT staff for selected cloud-based tools, applying appropriate adoption models like TAM or UTAUT, with particular emphasis on the specific challenges arising from remote and/or low-bandwidth access by displaced users.

3. Data residency hosted locally: To investigate the technical and legal feasibility of a locally hosted, dedicated data center for HEIs in Sudan, in order to address Data Sovereignty concerns, possibly as part of the proposed Community Cloud model.

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الملخص

تأثرت البنية التحتية للتعليم العالي في السودان بشكل كبير جراء الحرب الدائرة، مما أدى إلى حاجة ماسة لأنظمة قادرة على ضمان إستمرارية العملية التعليمية. تقدّم هذه الورقة مراجعة منهجية لإمكانات الحوسبة السحابية في تحديث الجامعات السودانية والتخفيف من آثار الدمار المادي والنزوح الجماعي للطلاب. بإستخدام إطار عمل (التقنية – المنظمة – البيئة) تركز هذه الدراسة على البحوث المنشورة من العام 2014 لتقييم الفوائد والتحديات والفرص الإستراتيجية لتبني الحوسبة السحابية في مؤسسات التعليم العالي السودانية محدودة الموارد. تؤكد النتائج بأن الانتقال إلى الحوسبة السحابية يوفر مزايا تحويلية من خلال تحويل تكاليف تقنية المعلومات من نفقات رأسمالية إلى نفقات تشغيلية، وتمكين المرونة التعليمية عبر استعادة بيانات فعالة في حالة حدوث الكوارث. ومع ذلك فإن تبني الحوسبة السحابية يواجه مشكلات كبيرة تتمثل في عدم استقرار اتصال الانترنت وانقطاع التيار الكهربائي والمخاوف المتعلقة بالسيادة على البيانات. تقترح الدراسة مسارات عمل محددة، تشمل تبني نماذج السحابة الهجينة والسحابة المجتمعية، بجانب تطوير سياسات وطنية بخصوص السيادة على البيانات، لمعالجة أوجه القصور وتأمين مستقبل التعليم العالي في السودان.