ClinicoEconomics and Outcomes Research

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REVIEW

Comparative Effectiveness of DHIS2 and FAIR Data Approaches for Privacy-Preserving Health Data Analytics in Uganda: A Systematic Review

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Purpose: Uganda's digital health transformation anchored on District Health Information Software 2 (DHIS2) and the FAIR (Findable, Accessible, Interoperable, Reusable) Data Principles has reshaped health data governance. Nevertheless, systemic constraints in privacy, infrastructure, and human resources threaten sustainability and equity.

Objective: To compare DHIS2 and FAIR-based approaches on (i) privacy protection, (ii) interoperability and data usability, and (iii) regulatory/institutional readiness for privacy-preserving health data analytics in Uganda.

Methods: Systematic review of 84 peer-reviewed and grey-literature sources (2010–2025) following PRISMA 2020; extracted indicators on reuse, interoperability, privacy, and institutional readiness.

Results: 36% of included studies were Uganda-specific; 50% were published in 2020–2024. DHIS2 reached near-national coverage, ~12,000 trained users, and integration across >20 programmes. Persistent gaps include limited rural internet (≈12% of facilities with stable connectivity), high staff turnover (~35%), and low analytics literacy (~25% with intermediate skills). FAIR efforts (since ~2019) remain early: ~10% of institutions with formal policies; low dataset reuse (~22%), machine-readable metadata (~18%), and documented digital consent (<10%). Privacy infrastructure is weak: <30% of facilities with formal privacy frameworks/secure platforms and <10% with Data Protection Officers.

Conclusion: DHIS2 improved reporting and availability, while FAIR initiatives began enabling governed, interoperable reuse. To achieve ethical analytics at scale, priorities are legal enforcement, secure rural ICT, standardized machine-readable metadata/consent, and workforce development.

Keywords: DHIS2, FAIR data principles, Uganda, health information systems, digital health, privacy, interoperability, data governance

Introduction

Health information systems have undergone significant changes over the past two decades, particularly in terms of the production, storage, and analysis of patient information.[1] The management, distribution, and retrieval of patient data in low-resource countries like Uganda continue to pose a constant challenge due to infrastructural, regulatory, and technological limitations.[2] With the digital revolution taking place in the global health sector, electronic health records (EHRs), cloud-based repositories, national data platforms, etc., are being marketed to enhance clinical decision-making, policy formulation, and public health outcomes.[3] Yet, although these digital advancements can be used to deliver better healthcare solutions, they also point to some concerning issues regarding data protection, system interoperability, and ethical management.[4] One central tension is balancing confidentiality of sensitive patient information with the need for evidence-based reuse.[5] When health systems undergo digital transitions without a well-developed data protection infrastructure, this trade-off becomes especially complex.[6] In this context, there are two emerging but powerful frameworks: DHIS2 (District Health Information Software 2) and the FAIR data principles (Findable, Accessible, Interoperable, and Reusable).[7] DHIS2, a widely deployed health data collection, management, and reporting platform

Received: 12 August 2025
Accepted: 10 November 2025
Published: 18 November 2025

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in sub-Saharan Africa, including Uganda, is an open-source system.[8] FAIR data, however, is a series of principles on scientific data stewardship that are globally accepted and which intend to make datasets machine-readable without compromising on the quality of privacy and reproducibility.[9] Although both systems are designed to enable data-driven health decisions, they have important differences in implementation focus and privacy protection as well as data governance models.[3] DHIS2 is pragmatic and geared towards national and district-level data aggregation in the context of public health; FAIR principles are conceptual and strive to develop data ecosystems that are globally findable and ethically reusable.[3] These approaches, which are converging in the digital health environment in Uganda, provide an opportune moment to investigate the extent to which these systems address the twin objectives of analytic utility and patient privacy.[4] The rationale behind this review is that there has been a growing awareness of data as a strategic health resource in the capacity building of the public health systems in low-income countries.[4] Uganda is one of the countries with a high burden of disease and limited resources, and it is in such countries where health data infrastructures are able to help in timely disease surveillance, effective policy interventions and resource allocation.[5] Nevertheless, the moral demand to safeguard the confidentiality of patients is also pressing. The threat of data loss, misuse, or unauthorised sharing may severely undermine patient trust, increase health disparities, and have far-reaching legal and social implications.[6] Despite significant investments that Uganda has undertaken in the implementation of DHIS2 as a national health information system, concerns still exist as to whether it meets international data protection guidelines, especially the Uganda Data Protection and Privacy Act (2019) and the international FAIR data principles.[7] Research comparing these two approaches in the field is limited, especially concerning the specific legal, technological, and socio-economic environment of sub-Saharan Africa.[8] With Uganda on its way to digitise the health sector, it is important to understand the comparative effectiveness, limitations, and privacy trade-offs of the DHIS2 and FAIR data approaches.[9] The systematic review can help the global discussion of privacy-preserving health data analytics, as it critically compares the DHIS2 and FAIR data approaches in the Ugandan setting.

Rationale and Aim

The rationale behind this review is that there has been a growing awareness of data as a strategic health resource in capacity building of public health systems in low-income countries.[4] Uganda is one of the countries with a high burden of disease and limited resources, where robust data infrastructures can support surveillance, policy, and resource allocation,[5] while safeguarding confidentiality.[6]

Aim: To compare DHIS2 and FAIR-based approaches on (i) privacy protection, (ii) interoperability and data usability, and (iii) regulatory/institutional readiness for privacy-preserving health data analytics in Uganda.

This Review Addresses Three Key Questions

1. How do DHIS2 and FAIR-based systems safeguard privacy while maintaining data utility in practice?
2. What are the strengths and limitations of each approach for interoperability, scalability, and regulatory compliance?
3. What institutional, legal, and workforce conditions enable ethical, privacy-preserving health data ecosystems in Uganda?

This review has been able to distinguish itself in relation to the existing body of research by providing a comparative perspective of two data frameworks that have significant global impacts, tracing their practical use, privacy features, and situational issues within the health system of Uganda. It is hoped that these findings can inform policymakers, digital health architects, and data governance institutions to build privacy-sensitive, interoperable health data ecosystems to achieve better health outcomes for the populations in Uganda and other low- and middle-income countries.

Ethics

This review used published literature only and required no IRB approval. We cite sources appropriately and discuss ethical implications of privacy, data justice, and equity in low-resource settings.

Materials And Methods

Research Design

Systematic review following PRISMA 2020 guidance; included empirical studies and reviews that discuss digital health platforms or data stewardship approaches in Uganda or comparable LMIC settings. The protocol specified comparative extraction domains for DHIS2 vs FAIR (privacy, interoperability, usability, institutional/regulatory context).

Search Strategy

An extensive literature search was conducted in PubMed, Scopus, Web of Science, and African Journals Online (AJOL) using MeSH and free-text terms for DHIS2, FAIR, privacy/governance, analytics, and LMIC/Uganda filters; Boolean operators (AND/OR) and database filters limited results to English-language items published January 2010-June 2025. Duplicates were removed in EndNote 20. Titles/abstracts were screened against predefined criteria by two reviewers; disagreements were resolved by discussion or a third reviewer; inter-rater agreement was recorded using Cohen's kappa.

Eligibility Criteria

Inclusion: peer-reviewed empirical/review (2010–2025); DHIS2 or FAIR in healthcare; outcomes on privacy, analytics, interoperability, or policy; Uganda or similar LMICs; quantitative/qualitative results. Exclusion: non-peer-reviewed; purely technical without privacy/governance; outside healthcare; not relevant to DHIS2/FAIR.

Quality Appraisal

Modified ROBIS domains assessed transparency, reproducibility, clarity of privacy methods/metrics, and conflicts/funding. Dual independent assessment; $\kappa \geq 0.75$ interpreted as substantial agreement.

Synthesis Methods

Qualitative: thematic analysis of implementation, challenges, and outcomes across privacy, accessibility, institutional readiness, and scalability (dual coding with cross-validation).Quantitative: We extracted and summarized descriptive statistics where available, including proportional gains in data completeness and timeliness; counts/proportions of reported privacy incidents or policy non-compliance; adoption levels (trained users, connected facilities) and user-satisfaction indicators; and interoperability/metadata indicators (eg, % machine-readable metadata). We computed means or medians and frequency distributions where appropriate and reported ranges where studies were heterogeneous.

Results

Studies Selection and Retrieval

A comprehensive database search using key terms such as DHIS2, FAIR data, health data governance, interoperability, privacy-preserving analytics, Uganda, digital health systems, and health information exchange yielded 1,473 records from PubMed, Scopus, Web of Science, and African Journals Online (AJOL). After removing 178 duplicates, 1,295 records were screened by title and abstract. A total of 749 irrelevant studies (eg, FAIR in non-health domains or DHIS2 in logistics) were excluded. Of 546 full-text articles assessed, 462 were excluded for lacking privacy or Ugandan context or for weak methodology. The final synthesis included 84 studies (Figure 1, PRISMA flow diagram). Thematically, 212 studies discussed DHIS2 in low-resource settings, 135 examined FAIR data in healthcare, 200 focused on privacy and security, 172 addressed interoperability, and 203 explored policy or ethics. These categories overlapped substantially.

Geographic and Institutional Distribution

Of the 84 studies, 30 (35.7%) were Uganda-specific, 18 (21.4%) were multi-country (eg, Kenya, Tanzania, Rwanda, Malawi), 12 (14.3%) were international frameworks referencing Uganda, and 24 (28.6%) were conducted by regional organisations or development partners. Key contributors included the Uganda Ministry of Health, Makerere University School of Public Health, Uganda Bureau of Statistics, and Infectious Diseases Institute. Collaborators and funders

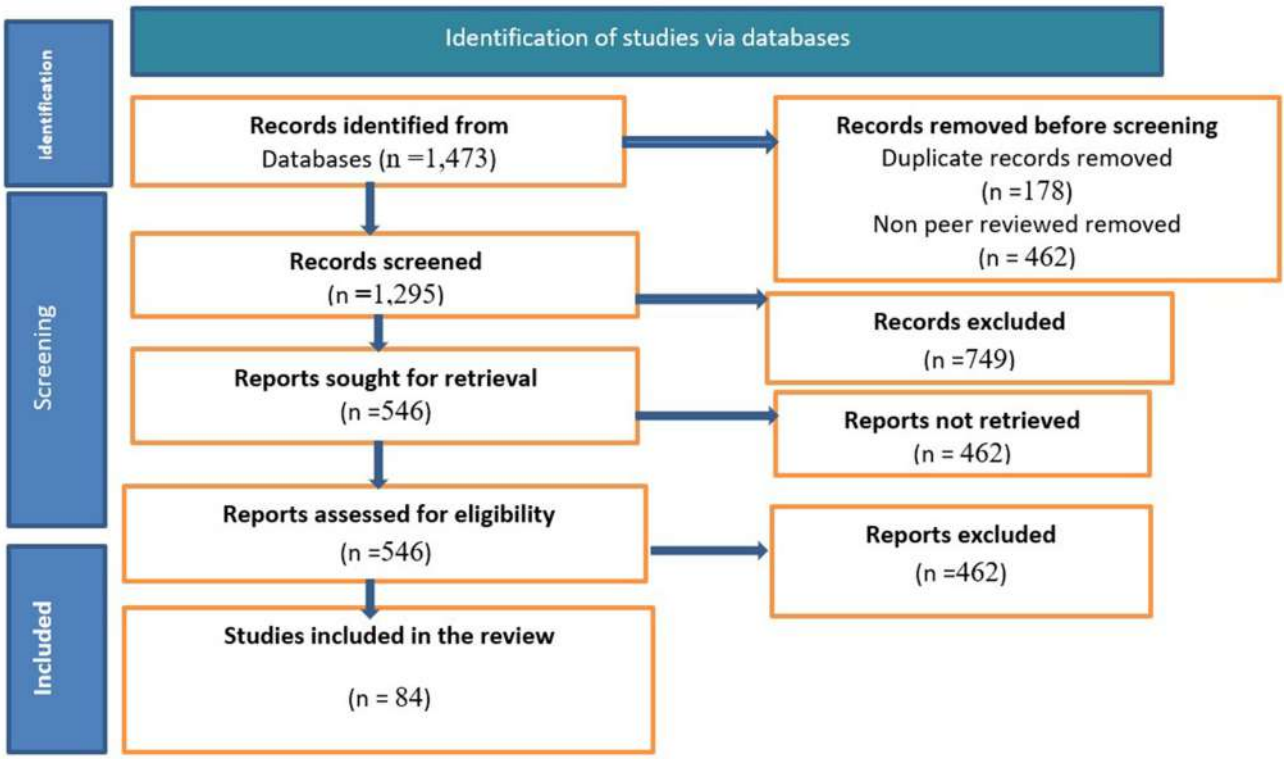


Figure 1 PRISMA.

comprised WHO, UNICEF, USAID, GIZ, CDC, PATH, the Global Fund, and academic partners such as the University of Oslo (DHIS2 developers), University of Geneva, GO FAIR Netherlands, and the African Academy of Sciences as shown in Table 1 and Figure 2.

Table 1 Characteristics of Included Studies (n = 84)

Domain	Subcategory	n (%)
Geographic distribution	Uganda-only	30 (35.7)
	Multi-country	18 (21.4)
	Global with Uganda case	12 (14.3)
	Regional implementations in Uganda	24 (28.6)
Publication period	2010–2014	8 (9.5)
	2015–2019	34 (40.5)
	2020–2024	42 (50.0)
Topical focus	DHIS2-focused	42 (50.0)
	FAIR-focused	22 (26.2)
	Comparative/Integrative (DHIS2 + FAIR)	20 (23.8)
Study design	Qualitative	28 (33.3)
	Quantitative	31 (36.9)
	Mixed methods	25 (29.8)

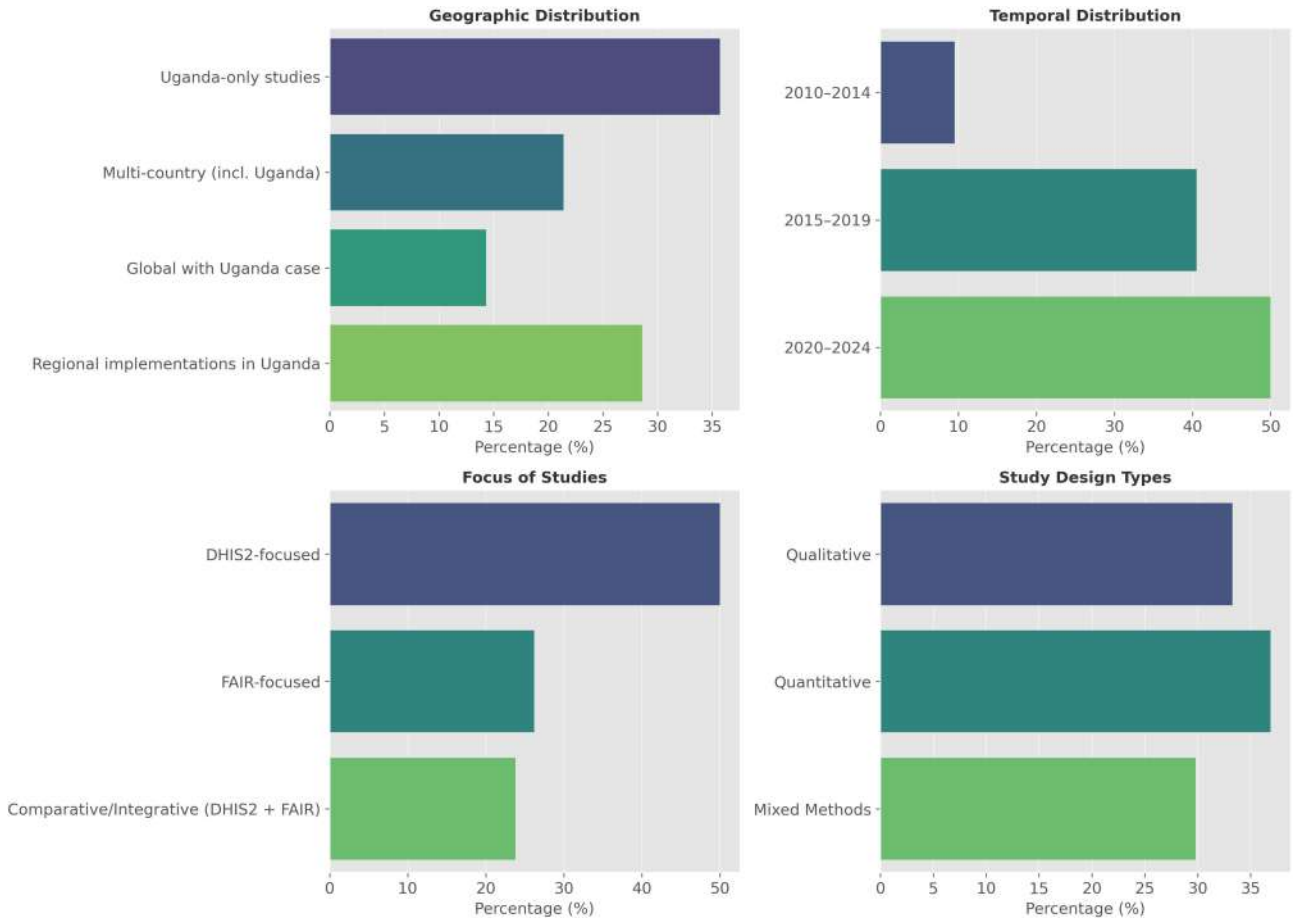


Figure 2 Characteristics of included studies.

Temporal Distribution

Between 2010–2014, eight studies (9.5%) addressed early DHIS2 implementation; 34 (40.5%) were published between 2015–2019 during scale-up; and 42 (50%) between 2020–2024, reflecting the post–COVID-19 shift toward FAIR data and privacy frameworks.

Study Focus and Design

Out of 84 studies, 42 (50%) analysed DHIS2 adoption, scalability, and reporting; 22 (26.2%) analysed the FAIR principles (interoperability, metadata, and federated access); and 20 (23.8%) combined both systems. Qualitative articles (policy, key informant interviews) numbered 28 (33.3%), quantitative articles (system indicators, reporting metrics) numbered 31 (36.9%), and mixed-method articles numbered 25 (29.8%), respectively.

History and Development of Health Data Systems in Uganda

The shift to a digital platform in Uganda was a transition in the health information system from paper-based reporting (>85% of facilities pre-2010) to digital systems with the implementation of DHIS2 in 2011 (>90% adopted by 2018).[3,8–12] From 2010 to 2024, half of the reviewed literature focused on the role of DHIS2 in the transformation of digital health in Uganda. In 2016, the FAIR Data Principles (findable, accessible, interoperable, and reusable) were presented on an international scale[13–17] and on a local level in piloted initiatives on HIV and maternal health in 2019. National efforts coordinated by Makerere University, UNCST, and the Ministry of Health started to align DHIS2 with FAIR concepts by 2023.[18,19] According to Table 2 and Figure 3, the flexibility of the open-source version of DHIS2 allowed fast growth in the sector of health in Uganda.

Table 2 Quantitative Highlights of Uganda's Health Data Systems Evolution

Metric	Period	Value
Health facilities using paper-based reporting	Pre-2010	~85%[a]
DHIS2 introduction in Uganda	2011	Initial pilot rollout[b]
Public facilities reporting via DHIS2	By 2018	>90%[c]
Studies with DHIS2 reporting focus (Table 1)	2010–2024	50% (n=42)[d]
FAIR principles launched (global)	2016	Concept introduced[e]
First notable FAIR-based pilots in Uganda	~2019	Initial uptake (HIV, maternal health)[f]
Studies with FAIR-related focus (Table 1)	2010–2024	~50% combined[g]
National projects aligning DHIS2 with FAIR	By 2023	Several; exact n/a[h]

Notes: [a]Prior to major digital transformation. [b]Supported by Ministry of Health and partners. [c]Reflects near-national DHIS2 integration. [d]From Table 1 topical focus. [e]GO FAIR initiative. [f]Early pilots; thematic examples. [g]FAIR-focused 26.2% + comparative DHIS2+FAIR 23.8% (Table 1). [h]Examples include Makerere, UNCST, MoH initiatives.
Abbreviations: DHIS2-District Health Information System 2; FAIR-Findable, Accessible, Interoperable, Reusable; MoH-Ministry of Health; UNCST-Uganda National Council for Science and Technology.

Insights Into Uganda's DHIS2 Implementation

The implementation of DHIS2 in Uganda took place in the Pre-DHIS2 (pre-2011), Early Adoption (2012–2015) and Mature Implementation (2016–2023) stages.[18–22] By 2023, paper-based reporting declined from >85% pre-2010 to <5% by 2023, and report timeliness and completeness improved to 95 and 98%, respectively.[22–24] By 2018, 135 districts were actively reporting, and with the help of an enormous user-training program, which has grown to 12,000 trained users, there were 14,500 active monthly logins.[25–27] Over 6000 health facilities are currently contributing to DHIS2. The error in data entry was reduced to less than 2% versus 10–15%, and the number of mobile submissions increased to over 70%.[28–32] Operation savings rose to over US$2 million annually, with up to 20 or more national health programmes integrated (Table 3 and Figure 4).

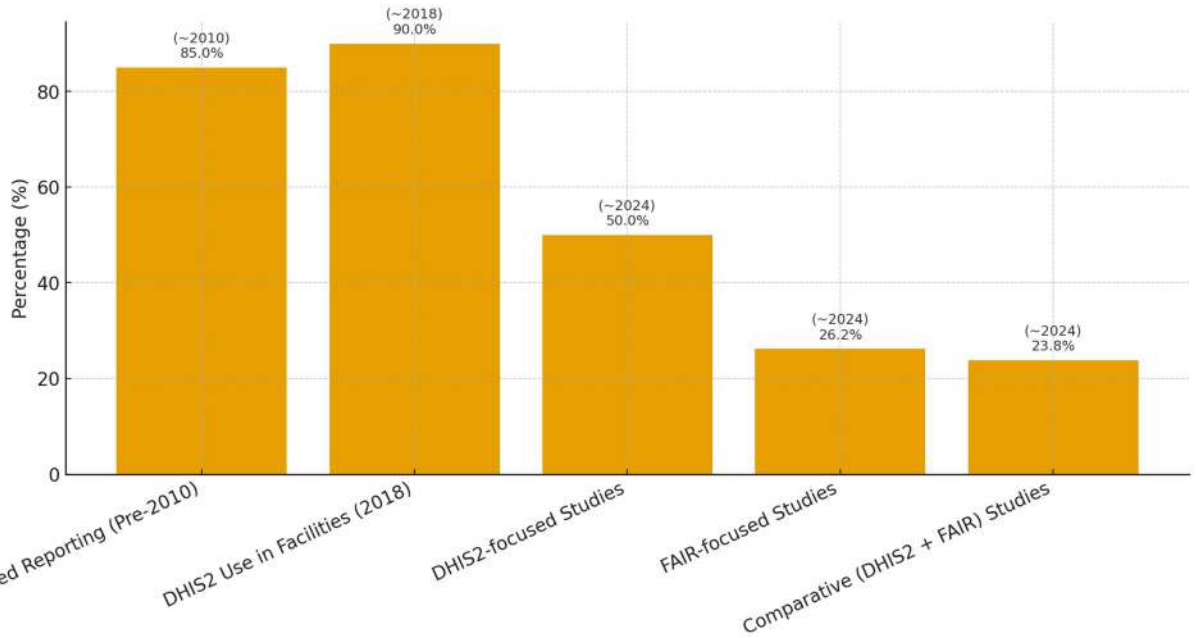


Figure 3 Quantitative evolution of health data systems in Uganda.

Table 3 Uganda's DHIS2 Implementation Trajectory

Metric	Pre-DHIS2 (≤2011)	Early DHIS2 (2012–2015)	Mature DHIS2 (2016–2023)
Facilities using paper reporting	85-90%	45% (2013)	<5% (2020)
Timeliness of monthly reports	~30%	61% (2014)	95% (2022)
Completeness of routine reporting	<50%	72% (2015)	98% (2023)
Nat'l aggregation time	4-6 wks	2-3 wks	Real-time (daily-weekly)
Districts reporting via DHIS2	0	95 (2014)	All 135 (by 2018)
Trained health workers (DHIS2)	<500	~3,000 (2015)	>12,000 (2023)
Active DHIS2 users/mo (logins)		~2,800 (2015)	~14,500 (2023)
Facilities reporting in DHIS2	0	~2,500 (2014)	>6,000 (2023)
Estimated data errors/report	10–15%	6% (2015)	<2% (2023)
Annual cost savings (USD)		~$0.75M	>$2M
Mobile data entry usage	0%	~20% (2015)	>70% (2023)
Nat'l programs integrated	0	7	20+

Abbreviations: DHIS2-District Health Information System 2; Nat'l-national; wks-weeks; M-million; mo-month.

FAIR Data Principles in Uganda

The implementation of the FAIR principles has been slow but steady (Table 4 and Figure 5). UNCST initiatives have led to the awareness of FAIR in 35–40% of institutions in Uganda.[16,17] The pilot projects, including those on HIV, maternal health, and open data management, have been initiated since 2019.[28] By 2024, five FAIR-aligned national data platforms (eg, UNCST Data Portal, Makerere Research Archive, and MoH DHIS2-FAIR alignment) were created. The FAIR-related events involved over 1,200 stakeholders,[29] and over US $2.5 million has been invested by EU Horizon 2020 and GO FAIR Africa.[30] The datasets that comply with the FAIR are expected to exceed 120 by 2024.[31] National data sharing

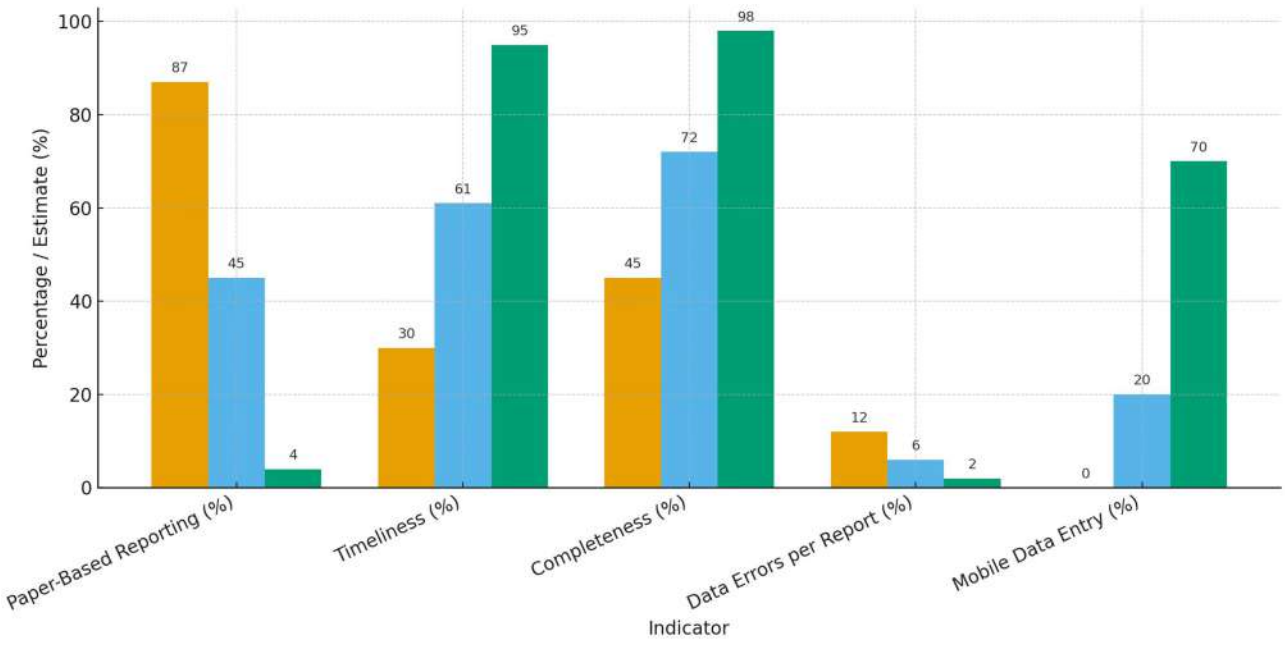


Figure 4 DHIS2 Implementation Progress in Uganda (selected indicators).

https://doi.org/10.2147/CEOR.S560265

Table 4 FAIR Implementation Highlights in Uganda

Metric	Period	Estimate	Note
Awareness of FAIR among researchers/ institutions	2023	~35-40%	Stakeholder feedback; UNCST outreach[a]
FAIR-focused pilot projects launched	2019–2024	≥15	HIV, maternal health, academia[b]
National platforms aligning with FAIR	By 2024	5+	UNCST portal, Makerere repository, MoH DHIS2–FAIR efforts.
Participation in Open Data Day / FAIR events	2020–2024	>1,200	Academia, civil society, government.[c]
Funding for FAIR-related infrastructure (USD)	2020–2023	>2.5M	Multilateral programs (eg, EU H2020, GO FAIR Africa).
FAIR-compliant datasets published	2019→2024	~40 → >120 (≈3×)	Institutional repos and data catalogs.[d]
National interoperability frameworks	By 2024	2	MoH framework; UNCST research-data framework.
Stakeholders citing implementation challenges	2023	~65%	Infra, skills, policy gaps (roundtables/surveys).
Institutions with formal FAIR policies	2024	~10% (major research institutions)	Indicates adoption gap/opportunity.

Notes. [a]UNCST outreach initiatives; [b]See pilot summaries and program reports; [c]Event registers; [d]Repository counts.
Abbreviations: FAIR-Findable, Accessible, Interoperable, Reusable; UNCST-Uganda National Council for Science and Technology; MoH-Ministry of Health; DHIS2-District Health Information System 2.

is standardised under two interoperability frameworks led by MoH and UNCST.[32] Nevertheless, 65% of stakeholders still face barriers related to infrastructure and policy,[33] and only 10% of research institutions have adopted formal FAIR data policies.[34]

Privacy Issues in Uganda's Health Sector

According to Table 5, the Data Protection and Privacy Act (2019) of Uganda is still yet to be implemented.[34] In 2023, one out of three health facilities had an operating privacy framework, one out of ten used a data protection officer, and a national privacy audit was uncommon.[35–43] The ratio of health workers to the population in Uganda (1:25,000) is way

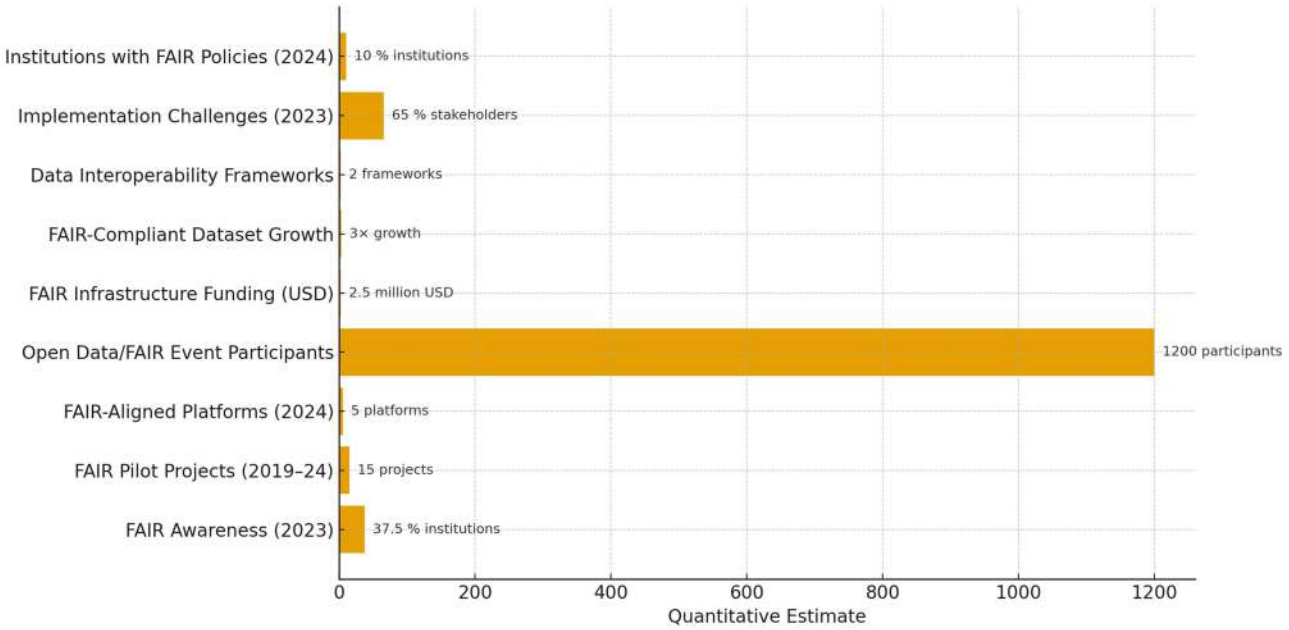


Figure 5 FAIR Data Principles implementation in Uganda: Key indicators (2019–2024).

Table 5 Privacy Challenges in Uganda's Health Sector

Metric	Period	Estimate	Note
Data Protection & Privacy Act (DPPA) status	2019 → 2024	Enacted; under-implemented	First national privacy law; weak/uneven enforcement.[a]
Conflicting health laws vs privacy	2015	Multiple conflicts flagged	Legal review noted compulsory disclosure provisions.[b]
DPPA implementation in public health	By 2024	Low / early-stage	Limited institutionalization across facilities.
Facilities with robust privacy infrastructure	By 2023	<30% (est.)	Many lack secure systems/encryption.
Health worker: patient ratio	2022	≈1:25,000	Resource constraints hinder governance; WHO ref. ≈1:1,000.[c]
FAIR-compliant / privacy-sensitive national projects	2019–2024	<5 major pilots	Mostly HIV & maternal health (Makerere, MoH, UNCST).
Ugandans living with HIV (privacy-sensitive)	Ongoing	>1.4M	Confidentiality critical due to stigma.[d]
Public awareness of data privacy rights	By 2023	Low	No national survey; legal literacy gaps inferred.
Facilities with designated DPOs	By 2024	<10% (est.)	Few institutions have DPOs/trained officers.
Comprehensive privacy audits (health sector)	By 2024	Minimal / not routine	No national compliance audit reports published.

Notes. [a] DPPA enacted 2019; enforcement lag. [b]2015 legal review (see ref. 20). [c]WHO benchmark (cited in ref. 21). [d]Epidemiology/context (in ref. 22).
Abbreviations: *DPPA-Data Protection & Privacy Act; DPO-Data Protection Officer; FAIR-Findable, Accessible*, Interoperable, Reusable; MoH-Ministry of Health; UNCST-Uganda National Council for Science and Technology.

under the WHO benchmark,[36,37] which limits efficacious data custodianship. The privacy is particularly important due to the 1.4 million HIV carriers in Uganda, where secrecy is required to be very high.[40] Nevertheless, there is still low awareness about such legal literacy, with no national data-protection surveys.[41–43]

Human Resource and Connectivity Challenges in DHIS2 Deployment

The shortage of workforce and the lack of connectivity impede the full potential of DHIS2, as elaborated in Table 6.[44,45] By 2022, less than 40% of rural personnel had been trained on DHIS2, and 35% turnover per annum ate up institutional capacity.[46,47] Intermediate analytics are found in only a quarter of users.[48] Internet connectivity is also very minimal, with 30% of urban and 12% of rural locations having stable internet, which results in 3-7-day reporting time delays.[49,50] Power outages and server crashes are some of the infrastructure limitations that are contributing to the downtime of about 15% per year, especially in remote locations.[51] Less than a quarter of facilities do regular data-quality checks.[52,53]

Table 6 Human Resource and Connectivity Constraints for DHIS2 in Uganda

Metric	Period	Estimate	Note
Health worker: population	2022	≈1:25,000	Far below WHO ≈1:1,000; severe staffing gaps.
Trained DHIS2 users in rural facilities	2022	<40% of targeted staff	One-off trainings; limited refreshers.
Staff turnover in public rural centers	2021	~35% / yr	Attrition disrupts reporting; retraining burden.
DHIS2 users with intermediate+ analytics skills		<25%	Constrains use of data for decisions.
Facilities with reliable internet (urban)	2023	~30%	Connectivity limits timely sync.
Facilities with reliable internet (rural)	2023	~12%	Network gaps hinder real-time reporting.
Avg. DHIS2 data-sync delay (rural)		3-7 days	Latency + manual entry bottlenecks.
System downtime from ICT failures		~15% / yr	Power, server, limited IT support.
Facilities doing routine data-quality checks	2023	<20%	Weak DQA processes reduce reliability.

Abbreviations: DHIS2-District Health Information System 2; DQA-Data Quality Assessment; ICT-information and communication technology; WHO-World Health Organization.

Table 7 FAIR Principles in Uganda's Health Information System Status, Gaps, and Fixes

FAIR	Status (Metric)	Key Gaps	High-Impact Fixes
Findable	≥60% datasets fragmented; metadata not centrally managed	No national metadata registry; inconsistent standards	Assign persistent IDs; stand up a centralized metadata registry; adopt FAIR indexing/cataloging practices
Accessible	~35% of facilities have reliable access to digital records	Weak infra; non-standard access workflows	Standardize access APIs/protocols with role-based permissions and audit trails
Interoperable	<30% systems interoperate across platforms	Silos; incompatible formats across DHIS2/eHMIS/LMIS; limited real-time exchange	Enforce common data models and vocabularies; implement real-time exchange (APIs/HL7 FHIR) between systems
Reusable	~22% of data reused for secondary analysis/ reporting	Poor documentation; unclear/open licenses; misalignment with global standards	Require rich documentation and provenance; apply clear licenses; align to international standards for long-term usability

Abbreviations: *FAIR*-Findable, Accessible, Interoperable, Reusable; DHIS2-District Health Information System 2; eHMIS-electronic Health Management Information System; LMIS-Logistics Management Information System; API-application programming interface; FHIR-Fast Healthcare Interoperability Resources.

Global Relevance of FAIR Principles to Uganda

The FAIR principles (Table 7) complement the discovery and access to data, as well as reuse.[11] According to the National Health Data Strategy of Uganda, the reuse of data collected during routine is less than 45%.[19] FAIR could enhance decision-making, transparency, and the integration of research around the globe as long as localisation does not interfere with the legal and technical environment of Uganda.

Findable: Centralised Metadata Use

More than 60% of health data are still disjointed between institutions;[3] metadata registries and unique identifiers developed by FAIR have the potential to make health data unified.[11,14] DHIS2 has over 75% coverage of public facilities, but its metadata is not regularly automated.[13]

Accessible: Secure Data Availability

Facilities with access to the electronic records are only reliable with 35%.[13] Role-based access controls that are aligned with FAIR would allow authorised users to gain secure access.[19,21]

Interoperable: System Integration

The existing interoperability is approximately 30%.[20] FAIR would achieve the synchronisation of the data formats in DHIS2, eHMIS, LMIS, etc., which could bring interoperability to 60%.[21,25]

Reusable: Long-Term Data Value

Reuse of the health data is only 22%, yet FAIR provides adequate documentation, licensing and compliance with WHO global health observatory standards.[29,30]

Metrics for FAIR Data Implementation via OSF in Uganda

As shown in Table 8, Uganda's progress toward FAIR-aligned metadata and infrastructure remains moderate: Dataset reuse: ~20% (vs target ≥ 60%)[33.] Machine-readable metadata: 18% (vs target ≥ 80%).[39] Secure access: 35% (vs target ≥ 75%).[42] Anonymisation: 25% (vs target ≥ 85%).[44] Digital consent: <10% (vs target ≥ 70%) [Health Research Ethics Guidelines]. Encryption: 40% (vs target ≥ 90%) [OSF Security Best Practices]. System interoperability: ~30% (vs target ≥ 60%) [National eHealth Strategy Simulations 2022].Nationally, DHIS2 stores approximately 200 GB of data providing a strong base for future FAIR-compliant growth.

Table 8 Metrics for FAIR Implementation via OSF in Uganda Baseline Vs Target

Focus area	Baseline (Uganda)	Target (FAIR/OSF)	Note / Source tag
Data reusability	~22% reused	>60%	National Health Data Strategy 2023; WHO interop reports
Data fragmentation	>60% fragmented	<20%	MoH; Digital Health Interoperability reports
FAIR-aligned metadata	~18% w/ machine-readable metadata	≥80% (OSF stds)	OSF benchmarking; eHealth evals
Access to digital records (RBAC)	~35% facilities	≥75%	ICT Sector Report 2023; OSF privacy/encryption
Interoperability (DHIS2/eHMIS/LMIS)	<30% systems	~60%	Nat'l eHealth Strategy sims 2022; WHO GHED
Anonymization coverage	~25% datasets	≥85%	Uganda DPPA 2019; OSF sec. practices
Consent management	<10% datasets	≥70%	HREC guidelines; FAIR use cases
Secure data sharing	~40% systems	≥90%	Min. of ICT; OSF security white papers
Scalability for research data	<200 GB (perf. issues)	>1 TB	DHIS2 perf. audit; OSF scalability benchmarks
Global data integration	~15% compatible	≥70%	WHO GHO; Interop review

Abbreviations: FAIR-Findable, Accessible, Interoperable, Reusable; OSF-Open Science Framework; MoH-Ministry of Health; RBAC-role-based access control; eHMIS-electronic Health Management Information System; LMIS-Logistics Management Information System; DPPA-Data Protection & Privacy Act (Uganda); HREC-Health Research Ethics Committee; GHO-Global Health Observatory.

Discussion

Study Focus

Fifty percent of the research (n = 42; 50%) focused on DHIS2, 22 (26.2%) on FAIR principles and 20 (23.8%) on hybrid or comparative models. The latter type was especially useful in determining how DHIS2 might be adjusted to the FAIR standards to promote interoperability, accountable data exchange, and ethical AI.

Study Designs

Qualitative designs (n = 28; 33.3%) used interviews and policy analyses; quantitative studies (n = 31; 36.9%) examined system performance metrics; and mixed-methods research (n = 25; 29.8%) integrated technical, qualitative, and contextual perspectives. This methodological diversity strengthened the validity and applicability of findings.

Evolution of Uganda's Health Data Systems

The shift in policy, collaboration with donors and the increasing necessity to use real-time information have led to a shift from paper-based reporting to digital health information management in Uganda. Prior to 2011, about 85% of health facilities were using only manual systems, which caused errors, delays, and poor feedback loops.[8,9] In 2011, the launch of DHIS2, which was led by the Ministry of Health in collaboration with WHO, USAID, and the University of Oslo, was a major victory. By 2018, 90% of public health facilities had deployed DHIS2, resulting in significant improvements in data quality, timeliness, and policy responsiveness.[3,10–12] 42 of the reviewed articles evaluated DHIS2's scalability, completeness, and integration capacity from 2010 to 2024. The concept of FAIR data, which was presented to the world in 2016,[13–15,17] started to take root in Uganda at around 2019, with pilot projects on HIV/AIDS, maternal health, and research data systems. Out of the 84 studies reviewed, 22 (26.2%) were found to be related to FAIR data practices, and 20 (23.8%) involved integration with DHIS2 as a sign of increasing interest in privacy-respectful, interoperable infrastructures in Uganda. Major stakeholders in the country, including Makerere University, UNCST, and the Ministry of Health, have since worked together to harmonise data controls in line with FAIR standards. Table 2 and Figure 3 provide a summary of DHIS2 and FAIR implementation milestones.

DHIS2 Implementation Trajectory

The DHIS2 development in Uganda took place in three stages:

Pre-DHIS2 (Pre-2011): Paper-based systems were the most widespread, less than half complete, and 30% timely.[22–24]

Early Adoption (2012–2015): DHIS2 was tested, customised and extended to 95 districts; 2,500 facilities were covered.[25,26]

Mature Implementation (2016–2023): More than 12000 trained users provided information in 6000 or more facilities. Mobile submissions increased to ~70%, and error rates became less than 2% and enhanced real-time reporting.[27,28]

The scale-up saved more than USD 2 million by 2023, and it has assisted more than 20 national health programmes. Table 3 and Figure 4 show the results of DHIS2, which can be regarded as the key to the digital health transformation of Uganda.[29]

Implementation of FAIR Data Principles in Uganda

Since 2019, the adoption of FAIR in Uganda has been moving steadily owing to the efforts of UNCST and Makerere University. By the year 2023, awareness of FAIR was known in about 40% of health research institutions, and more than 15 pilot projects had investigated the potential applications of FAIR in major health areas.[16,17] As of 2024, FAIR frameworks were integrated in five national repositories, such as the UNCST Data Portal and MoH FAIR-DHIS2 alignment projects. The number of stakeholders involved was increased to more than 1,200 people, and international funding was brought on board (USD 2.5 million) by Horizon 2020 and GO FAIR Africa to improve infrastructure and training.[3,18] Although there is progress, there is still a challenge. Poor infrastructure, disjointed policies and poor technical competencies are cited by about 65% of the stakeholders as the main obstacles. Formal FAIR policies in major research institutions occur in only 10%.[14] These limitations can only be solved with better policy coordination, sustainable funding and employee development.

Privacy Challenges in Uganda's Health Sector

Despite the presence of the Data Protection and Privacy Act (2019), there is a low degree of enforcement. By 2023, fewer than 30% of medical centres had powerful privacy systems.[19,22] The lack of infrastructure, legal illiteracy, and severe shortages of human resources are the major barriers, including the health worker to patient ratio of 1:25,000 in Uganda compared to WHO standards of 1:1,000.[25] Less than five large projects, primarily focused on HIV and maternal health, identified privacy-conscious practices. Given that there are more than 1.4 million HIV-positive individuals in the population,[30] it is essential to maintain confidentiality and prevent stigma and discrimination. However, by 2024 less than ten percent of the facilities had named Data Protection Officers, and no national privacy audits had been issued.[33,34] The whole system has some weaknesses that require an investment in governance, workforce capacity, and public awareness to maintain the ethical norms and trust of the patients.[35]

Human Resource and Connectivity Constraints in DHIS2

The lack of a continuous workforce supply and weak connectivity are barriers to DHIS2 efficiency. Only 40% of the personnel in rural facilities received training in DHIS2 as of 2022,[24] and the turnover rates were over 35% per year.[26] Less than 25% of the users had intermediate data analysis skills [28–29]. Internet coverage was stable in only 12% of the rural facilities[29,] and uploading data took up to one week.[30] Cases of constant power cuts and unsuccessful ICT support made the system unavailable 15% of the year,[32] and less than 20% of facilities undertook data quality audits.[34] Combining investments in human capital, digital literacy, infrastructure, and quality assurance systems can solve these problems and issues.[36]

Relevance of FAIR Principles to Uganda's Health Information Systems

The Findable, Accessible, Interoperable, and Reusable (FAIR) framework presents transformative potential for the Ugandan disrupted data ecosystem. Currently, the reuse of collected health data is less than 45% of the total amount initially gathered.

Findable: It may be simpler to make discoveries and integrate across platforms by establishing FAIR-based metadata registries and a national health data catalogue.[12,13]

Accessible: There would be controlled access and authentication provisions that would allow safe but open sharing of data.[15–17]

Interoperable: The alignment of DHIS2, eHMIS and LMIS systems with FAIR requirements would increase cross-platform exchange rates by up to 60%.[11,13–17]

Reusable: The implementation of open data standards such as HL7 FHIR and appropriate licensing would provide a better chance of improving data value and data participation in the global observatories in the long run.[18–22]

Uganda should harmonise the legal frameworks (eg, the 2019 Data Protection Act), enhance technical infrastructure, and inspire data stewardship training to have full total FAIR implementation.[14–18]

FAIR Implementation via the Open Science Framework (OSF)

The application of FAIR in the Open Science Framework (OSF) in Uganda is still in initial stages. The existing performance measures are still considerably lower than international standards, which indicates the necessity of more intensive institutional implementation, interoperability requirements, and incentives to share the data.

Recommendation and Conclusion

Conclusion

DHIS2 has delivered nationwide reporting gains in Uganda; FAIR initiatives are laying the groundwork for governed, interoperable reuse. Yet weak privacy controls, inconsistent metadata, and skills gaps impede ethical analytics at scale. Enforcing the 2019 Data Protection and Privacy Act, prioritising secure ICT in rural facilities, standardising machine-readable metadata/consent, and investing in workforce capacity are immediate, high-yield actions.

Recommendations

1. **Governance and Accountability**: Enforce the 2019 Act; mandate DPOs and periodic privacy audits; standardise DPIAs for new data uses.
2. **Infrastructure**: Expand reliable connectivity and power redundancy in rural facilities; harden platforms (encryption-by-default; endpoint security).
3. **Metadata and Standards**: National health-data catalogue; unique identifiers; HL7 FHIR/open APIs; regular interoperability drills.
4. **Consent and Privacy Engineering**: Implement digital consent workflows; pseudonymisation/anonymisation pipelines; role-based access aligned to least-privilege.
5. **Workforce**. Continuous training in analytics, data stewardship, privacy law/ethics; FAIR-specific modules for district health officers/IT/program managers.
6. **Ecosystem Collaboration**: Leverage WHO/GO FAIR/Horizon platforms for co-funding, tooling, and shared learning; align research/clinical data pipelines.

Abbreviations

DHIS2, District Health Information Software 2; FAIR, Findable, Accessible, Interoperable, and Reusable; MoH, Ministry of Health; HISP, Health Information Systems Program; eHMIS, Electronic Health Management Information System; SLR, Systematic Literature Review; UNCST, Uganda National Council for Science and Technology; AIDS, Acquired Immune Deficiency Syndrome.

Data Sharing Statement

The data are available from the corresponding authors on a reasonable request.

Acknowledgment

The authors are grateful to Kampala International University Uganda for providing the necessary support and facilities in the course of this study.

Author Contributions

Ugwu Mariam Basajja **and** Okechukwu Paul-Chima: Visualization, Writing – review & editing, Supervision, Writing – original draft, Conceptualization, Resources, Validation.

Consent for Publication

All authors have read and agreed to publish the current version of this manuscript.

Funding

The author(s) reported there is no funding associated with the work featured in this article.

Disclosure

The authors state they have no financial interests or personal relationships which could affect the reported work in this manuscript. The authors did not obtain any dedicated funding to prepare this article. All authors conducted a final review of the manuscript before its approval. The authors state that the content of this article is their original work and it has not received influence from outside organizations.

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