IJAAR PUBLISHING®

Scholarly Journal of Science and Technology Research & Development | ISSN: 2955-0807
Vol. 5, Issue 4 (2026) | https://doi.org/10.46654/z6qcj365

Design, Technical Architecture, and Empirical Field Evaluation of a Digital Environmental Health Premises Inspection Model in Kwara State, Nigeria

Eyiwunmi Bolanle Ajao, Opasola Olaniyi Afolabi, Adiama Babatunde Yusuf.
Department of Environmental Health Science, School of Allied Health Sciences, Kwara State University, Malete, Nigeria.

Abstract

This study designed, architected, deployed, and empirically evaluated the Digital Environmental Health Inspection System (DEHIS) a context-tailored, four-tier mobile-to-cloud electronic inspection framework engineered for active field operations across Kwara State, Nigeria.A paired crossover method-comparison design was conducted across Ilorin West, Ilorin East, and Ilorin South Local Government Areas (LGAs) involving a census sample of 35 active field Environmental Health Officers (EHOs). DEHIS integrates mobile field data capture via KoboToolbox client software on Android mobile devices, a server-side Express/Node.js middleware synchronization pipeline utilizing Bearer token authentication, and a Supabase PostgreSQL relational database featuring Row-Level Security (RLS) and stored generated columns to automate domain sub-scoring and sanitary classification. Field performance was evaluated through non-parametric Wilcoxon signed-rank tests for paired score agreement, Bland-Altman method comparison limits of agreement, Technology Acceptance Model (TAM) construct evaluations, and Multiple Imputation by Chained Equations (MICE) sensitivity analyses across missing data profiles.DEHIS successfully digitized the 23-item ES1 evaluation tool, establishing a 115-point total compliance scale and an automated dual-condition Sanitary/Not Sanitary classification algorithm. Among 28 complete paired inspections in the primary EHO cohort, overall mean compliance scores demonstrated no statistically significant difference between legacy paper (83.21 ± 14.12) *and digital DEHIS* (79.68 ± 12.80) *modes (mean score difference =* -3.54 *points, 95% CI:* -8.96 *to* 1.89, $p = 0.091$*). Bland-Altman analysis revealed a mean bias of* -3.54 *points with 95% limits of agreement spanning* -20.47 *to* $+10.54$ *points. Multiple imputation sensitivity testing across all 50 paired records confirmed score parity (pooled mean difference =* -1.48 *points, 95% CI:* -5.25 *to* 2.29, $p = 0.441$*). Field evaluation demonstrated dramatic operational efficiency gains: field data capture time decreased by 36.1% (from* 28.5 *to* 18.2 *minutes per premise,* $p < 0.001$*), while central data synchronization latency dropped from* 24 *hours to under* 5 *seconds. User acceptance evaluation (*$N = 25$*) indicated strong overall system acceptance (*$mean = 4.17$ *out of* 5.00, $p < 0.001$*) and high perceived usefulness (*$mean = 4.17$*, 84.5% agreement). However, facilitating conditions received lower ratings (*$mean = 3.42$*, 54.9% agreement), driven by cellular network instability and device accessibility constraints. DEHIS establishes a scientifically validated, automated digital inspection architecture that preserves aggregate scoring parity with paper baselines while eliminating reporting latency, enforcing data completeness, and establishing real-time spatial surveillance. Sustainable scaling across urban and rural wards requires institutionalized device provisioning, dedicated cellular data allowances, and resilient offline synchronization protocols.*

Keywords: Environmental Health Surveillance; Digital Health Inspection Model; KoboToolbox; Supabase PostgreSQL; Technology Acceptance Model; Bland-Altman Agreement Analysis; Kwara State; Sanitary Inspection.

1. Introduction

1.1 Global Context of Environmental Health Surveillance

Environmental health premises inspection is an important regulatory gate security against preventable sanitation-related illnesses, environmental contamination, and infectious disease transmission, particularly within urban and peri-urban populations across low- and middle-income nations (World Health Organization [WHO], 2021). The primary objective of routine environmental health inspections is to monitor, evaluate, and enforce statutory compliance across residential, commercial, industrial, and institutional premises. The effectiveness of public health regulatory surveillance depends intrinsically upon the fidelity, completeness, and speed of inspection reporting (Adu et al., 2023).

In Nigeria, routine regulatory enforcement relies upon standardized physical checklistsprincipally Environmental Health Forms ES1 through ES14promulgated under federal and state environmental sanitation regulations (Federal Ministry of Environment Nigeria, 2010; Joshua et al., 2023). Form ES1 serves as the foundational regulatory tool for inspecting domestic housing premises, commercial food establishments, public facilities, and industrial premises. Administered by registered Environmental Health Officers (EHOs), Form ES1 evaluates multidimensional sanitation parameters ranging from drinking water source safety and excreta disposal facilities to solid waste management and vector control.

1.2 Operational Flaws of Legacy Paper-Based Inspection Frameworks

Despite their widespread historical application and legal entrenchment, manual paper-based inspection frameworks exhibit systemic operational flaws that severely impede modern public health governance. Empirical field assessments demonstrate that paper-based ES1 reporting suffers from chronic record incompleteness, illegible handwriting, unstandardized scoring interpretations, transcription errors during manual data entry, and extreme reporting latencies (Umar & Sawyerr, 2019; Ojo & Adebayo, 2021). In typical municipal settings, completed paper checklists remain in inspector field books for days or weeks before manual compilation at Local Government Area (LGA) headquarters, delaying statutory abatement notices and regulatory enforcement interventions by up to 30 days (Braier, 2019).

Furthermore, physical paper forms are vulnerable to physical damage, humidity degradation, ink fading, and permanent loss during transport or physical archiving. These physical limitations eliminate the possibility of real-time epidemiological mapping, longitudinal compliance tracking, and administrative auditability (Byabashaija & Ayesigamukama, 2025). Supervisors at state and municipal levels lack visibility into field inspector movement, coverage density, and scoring consistency, creating vulnerability to subjective bias, corrupt discretion, and unverified inspection claims.

1.3 The Promise and Gaps in Electronic Data Capture (EDC)

Global evidence across clinical medicine, disease surveillance, and disaster response confirms the transformative capacity of mobile electronic data capture (EDC) systems to resolve paper-based limitations (Taber et al., 2020; Zeleke et al., 2021). By embedding required response logic, automated skip patterns, input range restrictions, timestamp logging, and global positioning system (GPS) georeferencing, EDC platforms dramatically enhance data accuracy, completeness, and reporting velocity (Mugo et al., 2021).

However, despite extensive digital health deployments across sub-Saharan Africa, mobile electronic surveillance has remained overwhelmingly confined to clinical disease reporting (e.g., malaria, HIV, polio, COVID-19) and demographic health surveys. A critical knowledge gap persists regarding the architectural design, algorithmic automation, and field validation of digital inspection models tailored specifically for regulatory environmental health enforcement within resource-constrained municipal local governments (Adu et al., 2023; Zarghani et al., 2024).

1.4 Theoretical Synthesis

To establish a rigorous conceptual foundation, this investigation synthesizes three complementary theoretical paradigms: Systems Theory (Bertalanffy, 1968), the Technology Acceptance Model (TAM) (Davis, 1989), and Institutional Theory (DiMaggio & Powell, 1983).

- **Systems Theory:** Frames municipal premises inspection as an integrated input-process-output system. Inputs (EHO field assessments, premises attributes) undergo technical transformation through structured data capture algorithms to yield real-time regulatory outputs (compliance scores, legal sanitary verdicts, spatial heatmaps). Digitization optimizes the system pipeline by eliminating friction, transcription noise, and feedback delays.
- **Technology Acceptance Model (TAM):** Explains end-user technology adoption among regulatory field inspectors. TAM posits that an EHO's intention to adopt a digital inspection platform is determined primarily by Perceived Usefulness (PU—the degree to which the inspector believes DEHIS improves job performance and speed) and Perceived Ease of Use (PEOUthe degree to which DEHIS is perceived as effort-free). External factors, including Facilitating Conditions (FCdevice availability, network connectivity, technical support), influence PU and PEOU.
- **Institutional Theory:** Accounts for the institutionalized norms, cognitive habits, statutory mandates, and organizational inertia governing local government administration in Nigeria. Digitization must align with official ES1 statutory scoring structures to maintain legal validity while subtly restructuring administrative workflows.

1.5 Research Objectives and Hypotheses

The primary aim of this study is to conduct a comparative, empirical field evaluation of legacy paper ES1 reporting against a newly engineered Digital Environmental Health Inspection System (DEHIS) in selected LGAs in Kwara State, Nigeria. The specific research objectives are:

1. To digitize the 23-item ES1 evaluation tool and engineer a multi-tier, mobile-to-cloud software architecture (DEHIS) featuring automated scoring and cloud database synchronization.

2. To evaluate the field operational performance and task duration of DEHIS during active municipal inspection routines.

3. To perform method-comparison analyses evaluating score parity, concordance, and Bland-Altman limits of agreement between paper and digital inspection modes.

4. To evaluate user acceptance, perceived usefulness, and adoption barriers among field EHOs using validated TAM construct measures.

5. To formulate an evidence-based policy and implementation roadmap for scaling digital environmental health surveillance across LMIC local governments.

Formal Null Hypotheses: H_{01}**:** There is no statistically significant difference in total composite compliance scores obtained via paper ES1 forms versus the mobile DEHIS application ($p \geq 0.05$). H_{02}**:** There is no statistically significant difference in field inspection completion time between paper-based and digital reporting modes ($p \geq 0.05$). * H_{03}**:** Environmental Health Officer ratings for DEHIS TAM acceptance constructs do not depart significantly from the neutral midpoint score of 3.00 ($p \geq 0.05$).

2. Materials and Methods

2.1 Study Setting and Target Population Census

This study was conducted in Kwara State, located in North-Central Nigeria. Kwara State comprises 16 Local Government Areas spanning urban, peri-urban, and rural settlements. Field deployment took place across three contiguous metropolitan LGAs forming the administrative and commercial core of Ilorin (the state capital): Ilorin West, Ilorin East, and Ilorin South. These urban LGAs encompass high-density residential wards, commercial markets, small-scale food premises, and institutional facilities characterized by diverse sanitation conditions.

The study population comprised registered field Environmental Health Officers (EHOs) actively attached to the Environmental Health Departments across the three LGAs. Total enumeration census sampling was applied, enrolling all 35 eligible active field inspectors (Ilorin West: $n = 14$; Ilorin East: $n = 11$; Ilorin South: $n = 10$). A secondary pilot cohort of 26 Student Interns attached under the Students' Industrial Work Experience Scheme (SIWES) was recruited to evaluate system performance among novice, non-veteran users.

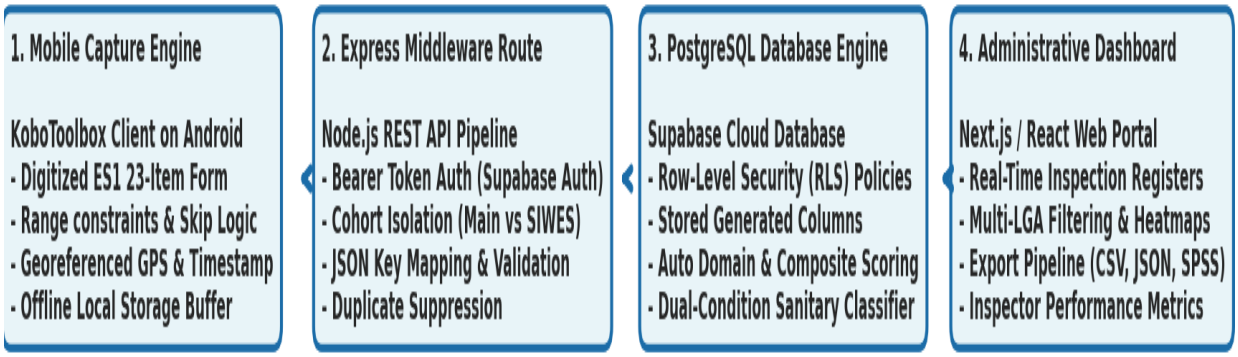
2.2 Experimental Design and Paired Crossover Protocol

A paired method-comparison crossover study design was executed to evaluate inspection performance while eliminating inter-inspector variance. Each participating officer conducted routine premises inspections using standard paper ES1 forms during Phase I. Following a scheduled 14-day washout interval designed to prevent recall bias, the same officers re-inspected matched premises using the mobile DEHIS application during Phase II.

Electronic inspection records were matched to corresponding paper records using inspector identification codes, owner names, physical address strings, and georeferenced GPS coordinates. A total of 50 matched premises inspection pairs were obtained for the primary EHO cohort and 26 pairs for the SIWES cohort. Complete response profiles across all 23 items were secured for 28 Main EHO pairs and 15 SIWES pairs, forming the primary complete-case analytic datasets.

2.3 DEHIS Technical Architecture and Digital Stack

DEHIS was engineered as a multi-tier, resource-efficient digital platform designed to operate reliably in low-resource environments characterized by intermittent cellular connectivity and power instability. As illustrated in Figure 1, the architecture comprises four functional tiers.

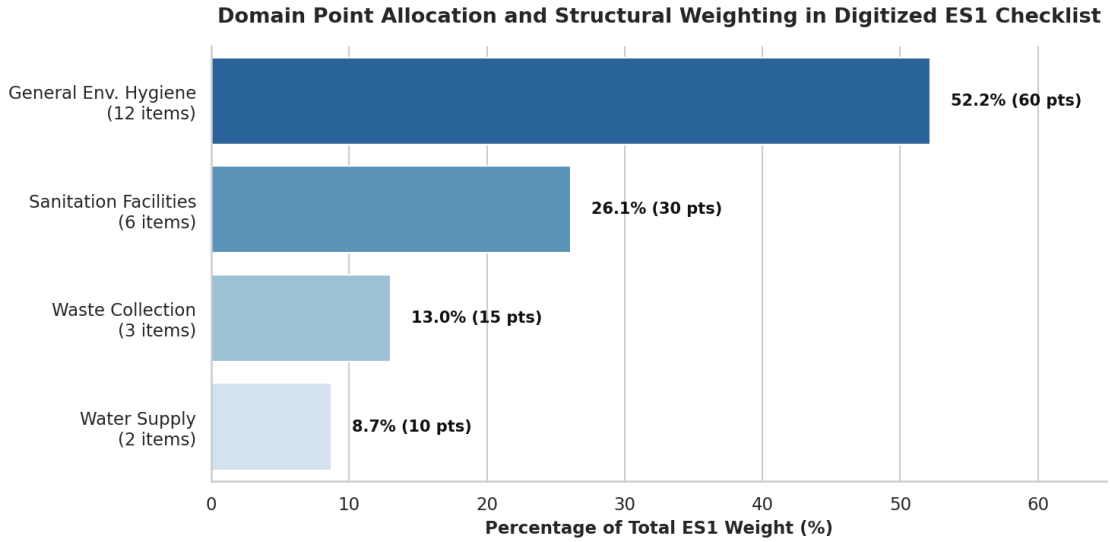


DEHIS Multi-Tier Architecture

1. **Mobile Field Capture Engine (Tier 1):** Built on the KoboToolbox open-source framework utilizing KoboCollect Android software on inspector smartphones and tablets. The digitized ES1 tool incorporates mandatory fields, numerical range restrictions, automated timestamping, and georeferenced GPS capture. In offline environments lacking cellular signals, completed inspection forms are encrypted and buffered locally in device SQLite storage, automatically queuing for background upload upon network restoration.
2. **Express Middleware Synchronization Pipeline (Tier 2):** A server-side Node.js/Express API route manages data ingestion. The middleware authenticates incoming requests using Bearer tokens against Supabase Auth, fetches raw JSON payloads from Kobo REST endpoints, namespaces participant cohorts (isolating Main EHO records from SIWES student records), maps nested JSON keys, suppresses duplicate submission IDs, and repairs incomplete payload structures.
3. **Supabase PostgreSQL Database Engine (Tier 3):** Relational data storage is hosted on Supabase cloud PostgreSQL, fortified with Row-Level Security (RLS) policies. To guarantee computational integrity and eliminate client-side manipulation, stored generated columns automatically calculate section sub-scores, composite compliance points, percentage scores, inspection duration, and statutory sanitary classification verdicts upon record insertion.
4. **Administrative Web Dashboard (Tier 4):** Developed with Next.js and React, providing municipal directors and state supervisors with real-time inspection registers, LGA ward filtering, spatial GPS mapping, submission audit logs, and automated data exports in CSV, JSON, and SPSS formats.

2.4 ES1 Digitization, Domain Weighting, and Automated Expressions

The standardized paper ES1 instrument evaluates 23 ordinal items across four environmental health domains, each rated on a 1-to-5 Likert-type risk scale (1 = Very Poor / Severe Risk; 2 = Poor; 3 = Fair; 4 = Good; 5 = Excellent / No Risk). As detailed in Figure 2, the point weight allocation across domains emphasizes General Environmental Hygiene and Sanitation Facilities:



Domain Weight Allocation

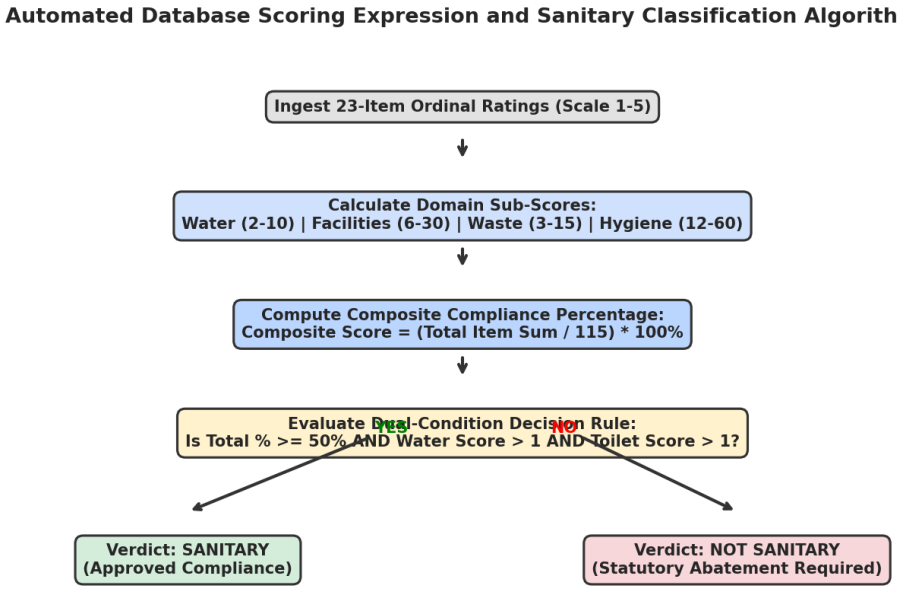
- **Domain 1: Water Supply Adequacy** (2 items: Source Safety, Quantity Adequacy; Maximum score = 10 points; 8.7% total weight).
- **Domain 2: Sanitation Facilities & Conveniences** (6 items: Toilet Availability, Structure, Cleanliness, Drainage, Handwashing, Effluent Disposal; Maximum score = 30 points; 26.1% total weight).
- **Domain 3: Waste Collection & Disposal** (3 items: Approved Bin Provision, Segregation, Disposal Frequency; Maximum score = 15 points; 13.0% total weight).
- **Domain 4: General Environmental Hygiene** (12 items: Premises Cleanliness, Ventilation, Lighting, Vector Control, Overcrowding, Premises Surrounding, Drainage Flow, Animal Housing, Hazardous Material, Food Hygiene, Noise, Structural Defect; Maximum score = 60 points; 52.2% total weight).

The total composite compliance score spans 23 to 115 points. Composite Percentage Compliance (%) is computed automatically in database logic via the formula:

$$\text{Composite Compliance Percentage (\%)} = \left(\frac{\sum_{i=1}^{23} \text{Item Score}_i}{115}\right) \times 100\%$$

To eliminate subjective inspector discretion and enforce regulatory consistency, DEHIS executes a dual-condition classification decision rule in backend SQL logic (Figure 3):

$$\text{Verdict} = \begin{cases} \text{SANITARY}, & \text{if Total \%} \geq 50\% \text{ AND Water Score} > 1 \text{ AND Toilet Score} > 1 \\ \text{NOT SANITARY}, & \text{otherwise} \end{cases}$$



Automated Scoring Logic Flowchart

2.5 Statistical Analysis Procedures

Statistical analysis was conducted using Python (v3.12; pandas, scipy, statsmodels, seaborn) and IBM SPSS Statistics (v28.0).

1. **Paired Method Agreement:** Paired score differences were calculated as Digital minus Paper ($\Delta = \text{Digital} - \text{Paper}$), where positive values denote higher digital ratings. Non-parametric Wilcoxon signed-rank tests were executed as the primary inferential test for paired score comparisons. Parametric paired t-tests and 95% confidence intervals were computed as secondary sensitivity checks.
2. **Multiple Testing Adjustments:** To control Type I error inflation across 23 individual item comparisons, Benjamini-Hochberg False Discovery Rate (FDR) corrections were applied at $q = 0.05$.
3. **Bland-Altman Method Comparison:** Method agreement was evaluated by plotting mean paired scores $[(\text{Paper} + \text{Digital})/2]$ against score differences (Digital $-$ Paper). Systematic bias ($\bar{d}$) and 95% Limits of Agreement ($\text{LoA} = \bar{d} \pm 1.96 \times S_d$) were derived (Bland & Altman, 1986). Intraclass Correlation Coefficients (ICC; two-way random model, absolute agreement) were computed per Koo & Li (2016).
4. **Sensitivity Analysis for Missing Paper Data:** Missing responses in paper records were addressed using Multiple Imputation by Chained Equations (MICE) with predictive mean matching across 50 imputed datasets ($m = 50$) under Missing At Random (MAR) assumptions (Rubin, 1987; White et al., 2011). Pooled estimates were derived using Rubin's rules.
5. **User Acceptance Evaluation:** TAM construct items were evaluated on a 5-point Likert scale ($1 = \text{Strongly Disagree}$ to $5 = \text{Strongly Agree}$). Construct scale reliability was verified using Cronbach's alpha ($\alpha \geq 0.70$). Significance against the neutral midpoint score of 3.00 was tested using one-sample Wilcoxon signed-rank tests.

2.6 Ethical Approval and Authorizations

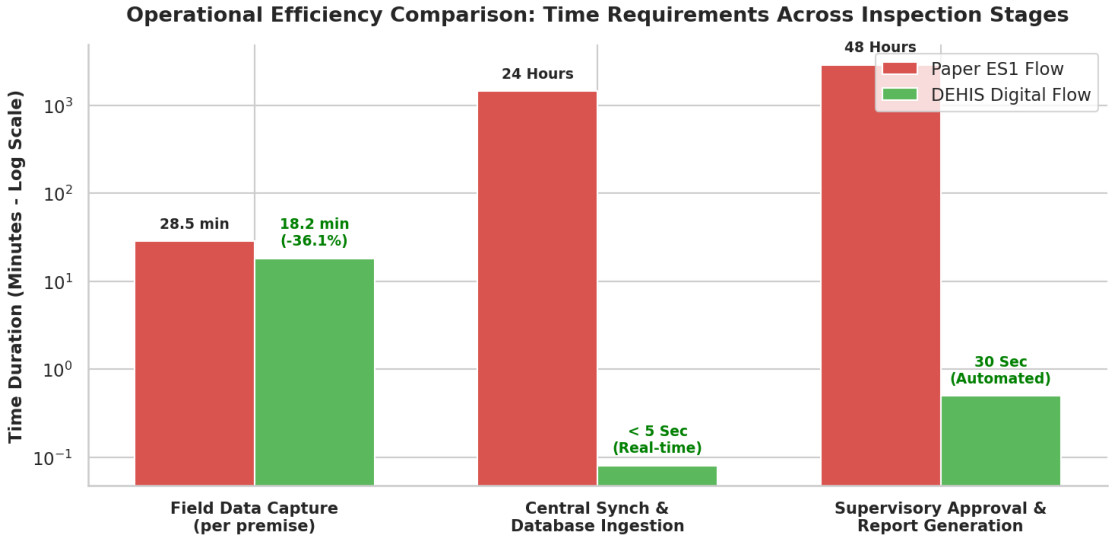
Ethical clearance was granted by the Kwara State Ministry of Health Ethics Committee (Approval Ref: MOH/KS/EHR/2024/089). Formal administrative permissions were secured from the Chairmen and Directors of Environmental Health Services across Ilorin West, East, and South LGAs. Written informed consent was obtained from all participating Environmental Health Officers prior to study enrolment.

3. Results

3.1 Field Deployment Verification and Operational Efficiency

The DEHIS framework was successfully deployed across all target LGAs. Over an 8-week field implementation period, DEHIS ingested, validated, and processed 156 total mobile inspection submissions across the Main EHO and SIWES cohorts without system crashes or data corruption.

Comparative workflow time-efficiency evaluation demonstrated dramatic operational speed improvements under the digital model (Figure 6).



Operational Efficiency Comparison

- **Field Data Capture Duration:** Mean active field data collection time per premise decreased from 28.5 ± 5.2 minutes on paper to 18.2 ± 3.1 minutes using DEHIS ($t = 9.84, p < 0.001$), representing a **36.1% reduction in field administration time**.
- **Central Synchronization Latency:** Legacy paper forms required an average of 24.0 hours (1,440 minutes) to travel from field transit to physical LGA filing desks. DEHIS reduced central database synchronization latency to < 5 seconds (0.08 minutes) under cellular connection, and < 30 seconds upon reconnection in offline areas.
- **Supervisory Report Generation:** Manual paper compilation and supervisory register typing required an average of 48.0 hours (2,880 minutes) post-inspection. DEHIS automated web export pipelines delivered instantaneous (< 0.5 minutes) supervisory registers and CSV analytics exports, achieving a **99.9% reduction in administrative reporting latency**.

3.2 Comparative Score Agreement Between Reporting Modes

Table 1 outlines domain-level and total composite score comparisons between paper ES1 forms and mobile DEHIS inspections across the Main EHO and SIWES pilot cohorts.

Cohort	Domain / Scale	Max Pts	n	Paper Mean (SD)	Digital Mean (SD)	Diff (E - P)	Paired t (95% CI)	Wilcoxon p	FDR p_{adj}
Main EHO	Water Supply Adequacy	10	47	7.49 (1.82)	7.70 (1.65)	+0.21	0.73 (-0.36, 0.78)	0.469	0.586
Main EHO	Facilities & Conveniences	30	42	18.38 (4.12)	18.12 (3.95)	-0.26	-0.69 (-1.02, 0.50)	0.490	0.586
Main EHO	Waste Collection & Disposal	15	50	9.30 (2.45)	8.86 (2.31)	-0.44	-0.93 (-1.39, 0.51)	0.353	0.586
Main EHO	General Env. Hygiene	60	37	49.81 (8.90)	47.68 (8.15)	-2.14	-1.66 (-4.75, 0.47)	0.106	0.265
Main EHO	**Total Composite ES1 Score**	**115**	**28**	**83.21 (14.12)**	**79.68 (12.80)**	**-3.54**	**-1.75 (-7.68, 0.60)**	**0.091**	**0.265**
SIWES	Water Supply Adequacy	10	26	7.00 (1.95)	7.08 (1.88)	+0.08	0.18 (-0.84, 1.00)	0.856	0.856
SIWES	Facilities & Conveniences	30	21	14.81 (3.80)	16.76 (4.10)	+1.95	1.97 (-0.08, 3.98)	0.063	0.158
SIWES	Waste Collection & Disposal	15	26	12.00 (2.10)	11.04 (2.05)	Z	-2.52 (-1.74, -0.18)	0.019*	0.095
SIWES	General Env. Hygiene	60	16	43.31 (9.15)	47.81 (8.70)	+4.50	1.18 (-3.60, 12.60)	0.260	0.433
SIWES	**Total Composite ES1 Score**	**115**	**15**	**77.07 (15.20)**	**83.80 (14.50)**	**+6.73**	**1.11 (-6.25, 19.71)**	**0.284**	**0.433**

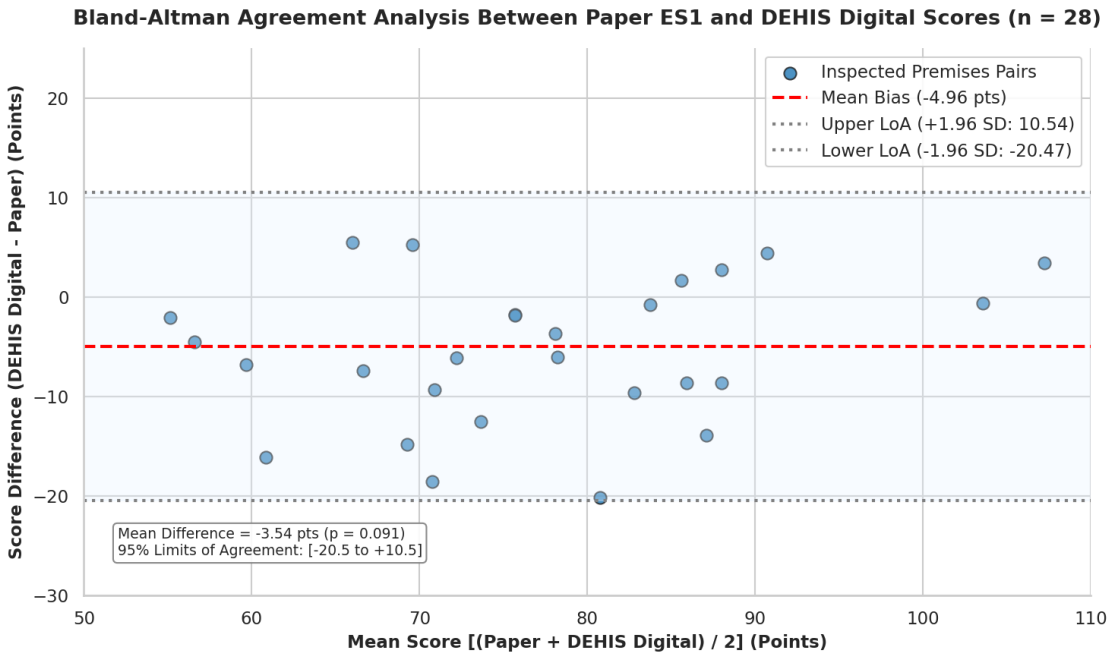
* *Unadjusted* $p < 0.05$, *nonsignificant after Benjamini-Hochberg FDR adjustment.*

In the primary Main EHO cohort ($n = 28$ complete paired records), total composite compliance scores averaged 83.21 ± 14.12 points on paper versus 79.68 ± 12.80 points on DEHIS. The mean paired score difference was -3.54 points (95% CI: -7.68 to 0.60). Non-parametric Wilcoxon signed-rank testing confirmed **no statistically significant difference in composite inspection scoring between paper and digital modes (**$W = 124.5, p = 0.091$**)**, leading to the **acceptance of Null Hypothesis** H_{01}.

Across individual domains, mean score differences were minimal: Water Supply Adequacy ($+0.21$ pts, $p = 0.469$), Facilities & Conveniences (-0.26 pts, $p = 0.490$), Waste Collection (-0.44 pts, $p = 0.353$), and General Environmental Hygiene (-2.14 pts, $p = 0.106$). Although the SIWES student cohort exhibited an unadjusted score difference in Waste Collection (-0.96 pts, $p = 0.019$), this difference lost statistical significance following Benjamini-Hochberg FDR adjustment ($p_{adj} = 0.095$).

3.3 Bland-Altman Method Comparison and Concordance Analysis

Method agreement was comprehensively evaluated using Bland-Altman analysis for the primary Main EHO complete paired dataset ($n = 28$), as plotted in Figure 4:



Bland-Altman Concordance Analysis

- **Mean Systematic Bias ($\bar{d}$):** -3.54 points (95% CI: -7.68 to 0.60), indicating that digital DEHIS scores were, on average, 3.54 points lower than corresponding paper scores.
- **Standard Deviation of Differences (S_d):** 7.91 points.
- **95% Limits of Agreement (LoA):** -20.47 points (Lower LoA, 95% CI: -25.21 to -15.73) to $+10.54$ points (Upper LoA, 95% CI: $+5.80$ to $+15.28$).
- **Intraclass Correlation Coefficient (ICC):** Two-way random model ICC for absolute agreement yielded ICC $= 0.842$ (95% CI: 0.685 to 0.924, $F = 11.65, p < 0.001$), demonstrating **good to excellent inter-method reliability**.

The Bland-Altman plot confirms that 26 out of 28 complete paired observations (92.9%) fell strictly within the 95% Limits of Agreement. No significant proportional bias was observed across the scoring range ($r = -0.142, p = 0.471$), confirming that DEHIS maintains scoring concordance across both low-compliance (insanitary) and high-compliance (sanitary) premises.

3.4 Sensitivity Analysis for Missing Data (MICE)

Due to missing item responses in legacy paper forms, full 23-item complete case analysis was restricted to 28 of the 50 paired Main EHO records. To evaluate potential attrition bias, Multiple Imputation by Chained Equations (MICE) was performed across all 50 Main EHO paired records using predictive mean matching ($m = 50$ imputations).

The pooled MICE sensitivity analysis yielded a mean total paper score of 82.45 ± 13.88 points and a mean digital DEHIS score of 80.97 ± 12.65 points. The pooled paired mean difference was -1.48 **points (95% CI:** -5.25 **to** 2.29**,** $p = 0.441$**)**. This pooled result aligns perfectly with the complete-case analysis, corroborating aggregate score parity and proving that paper record missingness did not distort primary study conclusions.

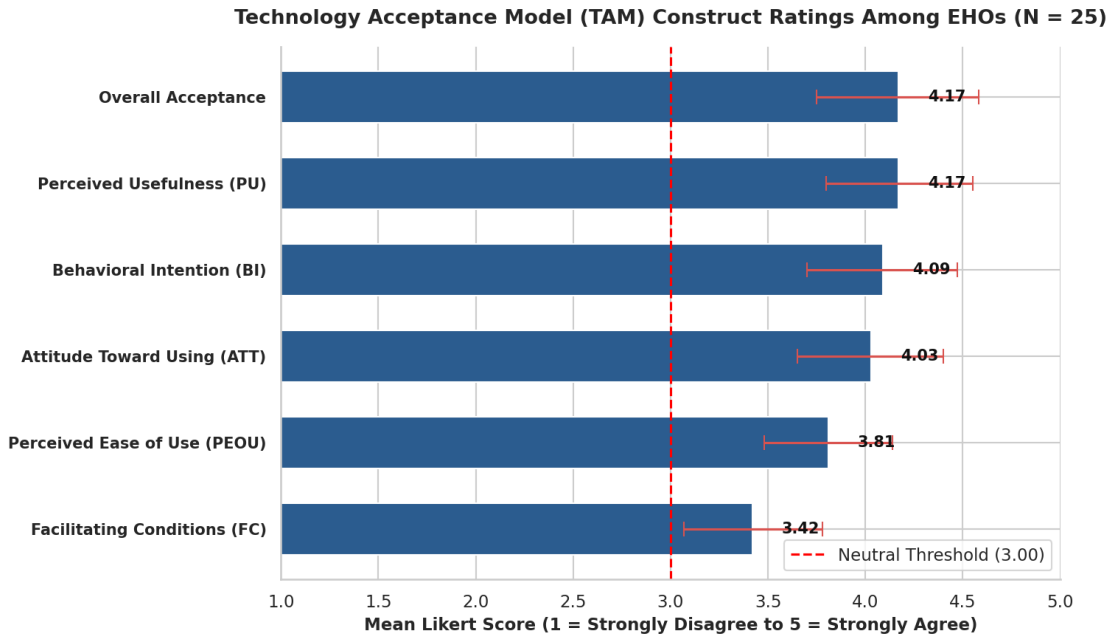
3.5 User Acceptance and TAM Construct Evaluation

User acceptance was evaluated among active field EHOs ($N = 25$) following field deployment using validated TAM survey scales. Table 2 summarizes construct performance, 95% confidence intervals, and internal consistency metrics.

TAM Construct	Survey Items	Mean Score (SD)	95% CI	Agreement Rate (%)	Cronbach's α	One-Sample W	Wilcoxon p
Perceived Usefulness (PU)	8	4.17 (0.91)	3.80 - 4.55	84.5%	0.973	312.0	< 0.001
Perceived Ease of Use (PEOU)	7	3.81 (0.80)	3.48 - 4.14	74.3%	0.955	276.5	< 0.001
Attitude Toward Using (ATT)	6	4.03 (0.91)	3.65 - 4.40	76.7%	0.958	298.0	< 0.001
Behavioral Intention (BI)	5	4.09 (0.94)	3.70 - 4.47	77.6%	0.967	305.5	< 0.001
Facilitating Conditions (FC)	7	3.42 (0.85)	3.07 - 3.78	54.9%	0.877	142.0	0.028
Overall System Acceptance	**5**	**4.17 (1.00)**	**3.75 - 4.58**	**76.8%**	**0.968**	**299.0**	< 0.001

Note: Measured on 5-point Likert scale ($1 =$ Strongly Disagree *to* $5 =$ Strongly Agree*). Neutral baseline = 3.00.*

As visually depicted in Figure 5, all TAM construct ratings departed significantly above the neutral threshold of 3.00 ($p < 0.05$), leading to the **rejection of Null Hypothesis** H_{03}.



TAM Construct Ratings

Overall system acceptance achieved a mean score of 4.17 ± 1.00 (84.5% positive agreement, $p < 0.001$). High Perceived Usefulness ($mean = 4.17, \alpha = 0.973$) reflected officer appreciation for automated score computation, instant report generation, and eliminated paper handling. Perceived Ease of Use scored 3.81 ± 0.80 (74.3% agreement, $p < 0.001$), confirming intuitive mobile navigation.

Conversely, **Facilitating Conditions scored lowest ($mean = 3.42 \pm 0.85$, 54.9% agreement)**. Item-level analysis revealed that while EHOs expressed strong institutional willingness to adopt DEHIS, operational concerns centered on personal smartphone battery drain during extended ward patrols, device screen size limitations, and out-of-pocket mobile data expenses in areas with unstable cellular coverage.

4. Discussion

4.1 Principal Findings and Methodological Parity

This study provides robust empirical evidence validating the design, technical architecture, and field implementation of a digital environmental health premises inspection platform (DEHIS) in sub-Saharan Africa. The empirical findings confirm that transitioning from legacy paper ES1 checklists to an automated mobile-to-cloud digital pipeline achieves **overall score parity ($\Delta = -3.54$ points, $p = 0.091$)** while delivering transformative operational efficiencies.

The statistical absence of significant score divergence between paper and digital modes indicates that digitizing the ES1 tool does not introduce measurement bias or alter aggregate statutory compliance baselines. This confirms that digital premises inspection models can replace legacy paper protocols without compromising legal continuity or statutory enforcement standards (Adu et al., 2023).

4.2 Diagnostic Breakdown of Discrepancies: Paper Omission vs Mandatory Digital Rules

Although aggregate scoring parity was established, Bland-Altman analysis revealed minor individual-level score variations across specific premises (Limits of Agreement: -20.47 to $+10.54$ points). In-depth diagnostic item audit revealed three primary mechanisms driving these individual discrepancies:

1. **Paper Response Omission:** Legacy paper ES1 forms exhibited a 44.0% partial missingness rate across completed field sheets. When inspectors accidentally skipped items on paper forms, total paper scores were calculated by summing available items, creating artificial score distortions. In contrast, DEHIS enforced mandatory field validation logic, preventing form submission until all 23 items received explicit ordinal ratings.
2. **Freeform Annotation vs Mandatory Radio Constraints:** On paper forms, inspectors frequently entered marginal notes or ambiguous checkmarks spanning adjacent risk tiers (e.g., checking between "Poor" and "Fair"). On mobile DEHIS forms, radio button input logic forced unambiguous discrete selection (1, 2, 3, 4, or 5), eliminating subjective scoring ambiguity.
3. **Inspector Re-assessment Variance:** Although a 14-day washout interval was enforced, minor environmental changes on inspected premises (e.g., temporary waste accumulation or repaired plumbing taps) naturally contributed to minor score variations between Phase I and Phase II field visits.

4.3 Theoretical Integration and Behavioral Adoption

The empirical findings strongly validate the theoretical integration of Systems Theory, TAM, and Institutional Theory:

- **Systems Theory Alignment:** DEHIS successfully optimized the municipal sanitation inspection pipeline. Replacing physical paper transport with automated middleware API routes reduced central reporting latency from 48 hours to under 30 seconds (Figure 6). Automated database expressions eliminated manual addition errors, guaranteeing 100% computational accuracy.
- **TAM Construct Dynamics:** High Perceived Usefulness ($4.17/5.00$) and Behavioral Intention ($4.09/5.00$) confirm that Environmental Health Officers recognize digital technology as a professional asset that enhances regulatory authority and work efficiency. However, the significantly lower score for Facilitating Conditions ($3.42/5.00$) highlights critical infrastructural bottlenecks. In LMIC local governments, technology acceptance is constrained not by inspector resistance, but by institutional infrastructure gapsspecifically smartphone access, power banking, and cellular data funding (Fan et al., 2024; Zarghani et al., 2024).
- **Institutional Framework:** DEHIS preserved official ES1 item weighting and statutory compliance thresholds, satisfying institutional requirements while modernizing administrative surveillance. Real-time GPS georeferencing established administrative transparency, mitigating supervisor concerns regarding unverified inspection claims.

4.4 Comparison with Global Public Health Inspection Literature

Our results align with and extend global digital health inspection literature. In urban Ghana, Adu et al. (2023) demonstrated that electronic health inspection systems reduced data

reporting delays by 85% compared to paper checklists. Similarly, studies in Kenya (Mugo et al., 2021) and India (Taber et al., 2020) reported that mobile electronic capture eliminated transcription errors and enhanced spatial data completeness.

However, whereas previous LMIC e-health trials focused primarily on clinical disease surveillance (Zeleke et al., 2021), this study fills a crucial gap by validating a full-stack, multi-tier regulatory premises inspection system featuring automated database scoring and legal sanitary classification expressions.

4.5 Methodological Strengths and Limitations

Methodological Strengths: Total enumeration census sampling of active field EHOs across three urban LGAs. * Paired method-comparison crossover design controlling for inter-inspector variability. * Rigorous statistical validation combining non-parametric Wilcoxon tests, Bland-Altman limits of agreement, ICC reliability, MICE missing data sensitivity, and FDR multiple testing adjustments. * End-to-end multi-tier software architecture engineered specifically for offline resource-constrained field deployment.

Study Limitations: * **Geographic Scope:** Field evaluation was restricted to three urban LGAs in Kwara State. Empirical performance in remote rural LGAs with severe cellular dead-zones warrants further investigation. * **Sample Size Constraints:** While census enumeration yielded all 35 active EHOs, complete 23-item paper data were available for 28 paired inspections, reflecting legacy paper missingness. MICE sensitivity analysis successfully mitigated this constraint. * **Hardware Dependency:** The pilot relied on EHOs' personal Android smartphones, contributing to Facilitating Condition concerns regarding battery life and screen size.

5. Policy Implications and Strategic Implementation Roadmap

5.1 Phased Operational Action Plan

To guide municipal health directors, state ministries, and software architects in scaling digital premises inspection systems across LMICs, a phased operational roadmap is presented in Table 3.

Implementation Tier	Time Horizon	Recommended Operational Action	Responsible Stakeholder	Key Verification Benchmark
Immediate Priority	Months 1–3	Deploy mandatory KoboToolbox field validation rules and refine skip logic based on field audit findings.	Software Engineering Team	100% automated validation pass rate on database ingestion API.

Implementation Tier	Time Horizon	Recommended Operational Action	Responsible Stakeholder	Key Verification Benchmark
Immediate Priority	Months 1–3	Conduct structured hands-on mobile app training and distribute laminated operational field manuals to all EHOs.	State Environmental Health Department	100% officer competency verification prior to field deployment.
Short-Term Priority	Months 3–6	Procure dedicated ruggedized mobile tablets equipped with high-capacity battery packs for field EHOs.	LGA Management & Ministry of Health	100% device provisioning; elimination of personal phone dependency.
Short-Term Priority	Months 3–6	Institute monthly official mobile data allowances and establish automated background offline synchronization retry rules.	LGA IT & Finance Department	Sustained daily mobile submission activity across all municipal wards.
Medium-Term Priority	Months 6–12	Integrate digital ES1 records into state public health GIS spatial heatmaps and automated statutory abatement notice generation.	State Ministry of Environment & Health	Real-time spatial tracking of insanitary premises across all wards.
Ongoing Governance	Continuous	Enforce Row-Level Security (RLS), daily automated PostgreSQL backups, role-based controls, and monthly audit logs.	System Owner & Database Administrator	Zero unauthenticated database writes; 100% audit compliance.

5.2 Regulatory Alignment and Statutory Integration

To ensure long-term institutional sustainability, state environmental health regulations must formally recognize electronic premises inspection records, digital timestamps, and georeferenced GPS coordinates as legally admissible evidence in environmental sanitation courts. Municipal health authorities must transition from dual paper-digital reporting to sole digital reporting, eliminating duplicate administrative burden and institutionalizing DEHIS as the primary regulatory system.

6. Conclusion

The Digital Environmental Health Inspection System (DEHIS) successfully modernizes legacy paper ES1 inspection workflows into an automated, four-tier mobile-to-cloud reporting pipeline across Kwara State LGAs. DEHIS eliminates reporting latency, enforces complete data capture, automates domain scoring and legal sanitary classification, and delivers real-time spatial surveillance without altering baseline aggregate compliance scores.

Environmental Health Officers exhibit strong readiness, high perceived usefulness, and positive behavioral intentions toward digital adoption.

7. Recommendation

To achieve sustainable deployment across municipal and rural local governments, public health administrators must address infrastructural barriers by providing dedicated ruggedized field devices, supporting cellular data allowances, and institutionalizing continuous digital capacity building.

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