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Data Quality and Administrative Time Efficiency of Smart Paper Technology versus Conventional Paper-Based Health Management Information Systems for Under-Five Immunisation Reporting: A Comparative Facility-Based Study in Lunga Lunga Sub County Hospital Kwale County, Kenya

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Abstract

Background. Routine immunisation data in low- and middle-income countries are frequently compromised by the fragmented, multi-register architecture of paper-based Health Management Information Systems (HMIS). Weaknesses in the completeness, accuracy and timeliness of these data undermine coverage estimation, defaulter tracing and vaccine stock management functions on which the Immunization Agenda 2030 targets depend. Smart Paper Technology (SPT) is a hybrid paper–digital innovation that preserves a familiar paper interface while adding automated scanning, validation and reporting. This study compared the data quality and administrative time efficiency of SPT against the conventional paper-based HMIS for under-five immunisation reporting in Kwale County, Kenya.

Methods. A comparative facility-based quasi-experimental design was used, contrasting an SPT-supported intervention site (Lunga Lunga Sub-County Hospital) with a conventional HMIS control site (Vanga Health Centre) over twelve months (July 2018–June 2019). One thousand five hundred patient-level immunisation records per site were sampled through systematic random selection and assessed against four dimensions of the World Health Organization Data Quality Review (DQR) framework: completeness, accuracy (verification factor), timeliness and consistency, using document analysis and cross-checking against the District Health Information Software 2 (DHIS2). Administrative time was measured with a time-and-motion protocol comprising 118 unobtrusive guided observations per site. Quality dimensions were summarised as proportions with 95% confidence intervals; time differences were tested with independent-samples t-tests and quantified with mean differences, 95% confidence intervals and standardised effect sizes.

Results. The SPT site outperformed the HMIS site on three of four quality dimensions: completeness (93.5% vs 82.5%), accuracy (verification factor 1.001 vs 1.11, the latter indicating approximately 10% under-reporting at the control site) and timeliness (100% vs 75% of monthly reports submitted on time). Record-to-DHIS2 consistency was the single dimension favouring the control condition (98.7% at the SPT site vs 93.2% against facility registers at the HMIS site), with the small residual gap attributable to a manual re-entry step. Mean first-time data-recording time was 4.0 minutes (SD 1.28) at the SPT site versus 9.9 minutes (SD 1.26) at the control site (mean difference 5.9 minutes, 95% CI 5.6–6.2; Cohen's d ≈ 4.6; $p < 0.001$), and mean data-processing time was 2.8 minutes (SD 0.60) versus 5.8 minutes (SD 1.18) (mean difference 3.0 minutes, 95% CI 2.8–3.2; Cohen's d ≈ 3.2; $p < 0.001$).

Conclusions. SPT delivered measurably superior immunisation data quality and roughly halved per-encounter administrative time relative to the conventional HMIS, with effect sizes that are very large by conventional benchmarks. The single point on which the conventional system held a marginal edge record-to-DHIS2 consistency reflects a solvable integration gap rather than an intrinsic limitation of SPT. Direct SPT–DHIS2 interoperability would be expected to close that gap and consolidate the data-quality case for wider adoption in comparable resource-constrained settings.

1. Background

Reliable routine health data are the foundation on which immunisation programmes are planned, monitored and held accountable. The value of any health information system is ultimately contingent on whether the data it produces faithfully reflect the service events that occurred in the field. Globally, this concern has been formalised in the World Health Organization (WHO) Data Quality Review (DQR) toolkit, developed with the Global Fund; Gavi, the Vaccine Alliance; and the MEASURE Evaluation project, which specifies completeness, internal consistency (including accuracy verified against source documents), timeliness and external consistency as the core dimensions against which routine health information systems should be judged (WHO, 2017). Data quality is likewise a cross-cutting enabler of the Immunization Agenda 2030, whose coverage and equity targets cannot be tracked, let alone acted upon, where the underlying reporting chain systematically omits, distorts or delays service data (WHO, 2020).

In much of sub-Saharan Africa and South Asia, immunisation reporting still rests on paper-based Health Management Information Systems (HMIS) in which a single service encounter is recorded across several parallel documents home-based child booklets, permanent registers, daily tally sheets and end-of-month summary returns before being aggregated by hand and entered into a national platform such as the District Health Information Software 2 (DHIS2). Each transfer point in this chain introduces an opportunity for omission, transcription error and delay, and the cumulative effect is a well-documented pattern of incomplete, late and internally inconsistent data (Endriyas et al., 2019; Ouedraogo et al., 2019; Kebede et al., 2020). The consequences are not merely administrative: under-reported doses depress apparent coverage and can trigger wasteful remedial campaigns, while over-reported doses conceal immunity gaps until they surface as outbreaks.

Fully electronic point-of-care systems have been proposed as a remedy, but their dependence on uninterrupted electricity, connectivity, device maintenance and sustained operating budgets has limited their durability in resource-constrained primary care settings (Kiberu et al., 2014). Smart Paper Technology (SPT) occupies an intermediate design space. Health workers continue to complete structured paper forms that mirror the documents they already use; these forms are subsequently scanned and digitised, with optical character recognition extracting the recorded values and routing illegible or incomplete entries to a dedicated verification station before they are committed to the digital record. The approach therefore preserves the low-barrier paper interface familiar to staff with limited digital exposure while capturing the auditability, speed and reporting automation of a digital backend.

In Kwale County, a coastal county of southern Kenya, SPT has been deployed since 2017 to support maternal, neonatal and child health services, with a particular focus on immunisation of children under five. Earlier programme reports suggested favourable completeness and timeliness, but these claims had not been subjected to an independent comparative evaluation against the conventional HMIS operating in neighbouring facilities. This study addresses that gap. It reports the first two of four pre-specified evaluation objectives data quality and administrative time efficiency comparing an SPT-supported facility with a matched conventional HMIS facility. The cost-effectiveness and health-worker acceptability objectives are reported in a companion paper.

The study was guided by two questions: (i) How does the quality of under-five immunisation data captured under SPT compare with that captured under the conventional paper-based HMIS across completeness, accuracy, timeliness and consistency? (ii) How do the administrative times required to record and to process immunisation data differ between the two systems?

2. Methods

2.1 Study design

A comparative, facility-based quasi-experimental design was adopted, contrasting a site operating SPT with a site operating the conventional HMIS over a twelve-month reporting window (July 2018–June 2019). The two systems were evaluated on identical data-quality dimensions and on directly comparable administrative tasks, with the conventional HMIS facility serving as the control condition against which SPT performance was benchmarked. Reporting of the quantitative strand follows the STROBE recommendations for observational comparative studies, adapted to a records-based evaluation.

2.2 Study area and sites

Kwale County comprises five sub-counties and is characterised by dispersed rural settlement, variable road quality and incomplete mobile-network and electricity coverage conditions typical of the settings in which immunisation programmes in the region operate. Two facilities were purposively selected to represent the contrasting data-management systems. Lunga Lunga Sub-County Hospital served as the intervention site, where SPT had been implemented for routine immunisation documentation. Vanga Health Centre served as the control site, where immunisation data continued to be managed through the standard paper-based HMIS and entered into DHIS2 by conventional means. The two facilities serve comparable coastal catchment populations and deliver the same package of under-five immunisation services.

2.3 Sampling and sample size

For the data-quality objective, immunisation records were drawn through systematic random sampling across the most recently completed quarters of the Kenyan fiscal year, yielding 1,500 patient-level records per site. The minimum requirement was derived from a two-sample comparison assuming 80% power, a 5% two-sided significance level, a standard deviation of 0.461 for immunisation data quality reported in a comparable East African setting and a moderate effect size, which returned at least 125 records per group; the achieved sample substantially exceeded this minimum, narrowing confidence intervals around the quality proportions. For the administrative time objective, the same power assumptions with an estimated standard deviation of 0.5 (from a pilot of HMIS data-management timing) returned a minimum of 118 observations per group, which was the number of guided observations completed at each site.

2.4 Data-quality measures

The four assessment dimensions were operationalised in line with the WHO DQR framework (WHO, 2017) and applied identically at both sites.

Completeness was defined as the presence of all required data elements in a record (Smerek, 2015) and was assessed against the original source documents at each site. The elements examined included the birth record (date, facility code, child identifier, date of birth, names of child and parents, sex, contact number, sub-location and village), the birth-update record, the child health form (date and type of vaccination, child identifier, age, health-worker name and signature) and the vaccine-management and data-for-action form. Completeness was expressed as the proportion of records in which all required fields were present.

Accuracy was assessed through a verification factor (VF), calculated as the ratio of recounted source-document totals to the totals reported in summary returns and DHIS2. A VF between 0.9 and 1.1 was treated as accurate; values below 0.9 signalled over-reporting and values above 1.1 signalled under-reporting warranting investigation.

Timeliness was measured as the proportion of monthly reports submitted on or before the mandated deadline (the fifth day of the following month), verified against submission records over the twelve-month window.

Consistency was assessed by cross-checking individual medical records against the corresponding DHIS2 entries, comparing fixed data elements (serial number and vaccination date) for agreement and expressing the proportion of records with concordant entries.

2.5 Administrative time measurement

Administrative time was captured using a time-and-motion protocol. Trained observers timed two routine tasks with a stopwatch: first-time data recording (the entry of a child newly introduced into the system) and data processing and reporting. Observations were conducted unobtrusively and sporadically across the study period, without prior notification to staff, to limit the Hawthorne effect and to capture realistic task durations. A standard time log recorded the start and end of each timed activity at both sites.

2.6 Data management and analysis

Records and observations were captured on Android devices using KoboCollect, synchronised to a cloud platform, exported to a spreadsheet database and imported into SPSS version 26 for analysis. Quality dimensions were summarised as proportions with 95% confidence intervals. Administrative times were summarised as means with standard deviations, minima and maxima; between-site differences were tested with independent-samples t-tests at a 5% significance level and are additionally reported as mean differences with 95% confidence intervals and standardised effect sizes (Cohen's d, computed from the group means, standard deviations and sample sizes) to convey the magnitude, and not merely the statistical detectability, of the observed contrasts.

2.7 Ethical considerations

The study received approval from the Board of Postgraduate Studies of Jaramogi Oginga Odinga University of Science and Technology (JOOUST), ethical clearance from the JOOUST Ethical Review Committee and a research licence from the National Commission for Science, Technology and Innovation (NACOSTI), with permission to access facilities granted by the County Director of Medical Services, Kwale County. Document analysis used de-identified, aggregate-level immunisation records, and all observational data were handled confidentially. No individually identifiable client information is reported.

3. Results

3.1 Completeness

Across the four record types examined, 93.5% (95% CI 92.7–94.3) of records at the SPT-supported site were complete, compared with 82.5% (95% CI 82.1–82.9) at the conventional HMIS site. At the SPT site, completeness by record type was 93.2% for birth records, 89.6% for birth updates, 94.1% for child health forms and 100% for the vaccine-management and data-for-action form. The conventional HMIS site recorded high completeness on some registers but markedly lower completeness on several routine forms, including the tally sheet, tetanus, vitamin A and long-lasting insecticidal net records (Table 1). The 11-percentage-point overall gap is therefore driven not by uniform under-performance at the control site but by the specific forms that require repeated, retrospective transcription precisely the documents that SPT's single-capture design eliminates.

Table 1
Data completeness by record type, SPT site (Lunga Lunga) versus HMIS site (Vanga)

Record / form	Complete — SPT n (%)	Complete — HMIS n (%)	Incomplete — SPT n (%)	Incomplete — HMIS n (%)
Birth record / permanent register	246 (93.2)	257 (97.3)	18 (6.8)	7 (2.7)
Birth update / tally sheet	129 (89.6)	913 (60.9)	15 (10.4)	167 (20.1)
Child health form	1016 (94.1)	15 (53.6)	64 (5.9)	13 (46.4)
Vaccine management & data-for-action	12 (100.0)	12 (100.0)	0 (0)	0 (0)
Tetanus	—	16 (42.1)	—	22 (57.9)
Vitamin A	—	13 (34.2)	—	25 (65.8)
Long-lasting insecticidal nets	—	12 (30.0)	—	28 (70.0)
Overall	1403 (93.5)	1238 (82.5)	97 (6.5)	262 (17.5)

Percentages for individual forms are calculated within each form type; overall figures are pooled across sampled records.

3.2 Accuracy

Over the twelve-month window, the SPT site returned an overall verification factor of 1.001 (2,101 reported against 2,104 recounted doses), indicating near-perfect concordance between reported and verified counts. The conventional HMIS site returned a verification factor of 1.11 (2,028 reported against 2,251 recounted), indicating that reported figures understated true service delivery by approximately 10% equivalent to some 223 administered doses over the year that never entered the official record. Monthly verification factors at the SPT site clustered tightly around unity, whereas those at the control site were consistently at or above the upper accuracy threshold, with several months exceeding 1.10 and a peak of 1.24 in June 2019 (Table 2). The direction of error at the control site was uniformly toward under-reporting in all twelve months, indicating a systematic rather than random loss of information along the manual aggregation chain.

Table 2
Reported and recounted immunisation doses with verification factors (VF), by month

Month	Reported SPT	Reported HMIS	Recounted SPT	Recounted HMIS	VF SPT	VF HMIS
Jul-18	190	225	193	231	1.016	1.03
Aug-18	150	192	150	209	1.000	1.09
Sep-18	293	179	293	198	1.000	1.11
Oct-18	157	182	158	212	1.006	1.16
Nov-18	143	135	143	149	1.000	1.10
Dec-18	106	114	106	127	1.000	1.11
Jan-19	139	152	138	167	0.993	1.10
Feb-19	160	188	160	208	1.000	1.11
Mar-19	171	156	171	182	1.000	1.17
Apr-19	186	219	186	249	1.000	1.14
May-19	186	195	186	206	1.000	1.06
Jun-19	220	91	220	113	1.000	1.24
Overall	2101	2028	2104	2251	1.001	1.11

VF = recounted ÷ reported. Values between 0.9 and 1.1 indicate acceptable accuracy; values above 1.1 indicate under-reporting in summary returns.

3.3 Timeliness

All twelve monthly reports from the SPT site were submitted on or before the mandated deadline, a timeliness rate of 100%. The conventional HMIS site submitted nine of twelve reports on time, a rate of 75%, with late submissions recorded in July 2018, January 2019 and April 2019 (Table 3).

Table 3
Monthly reporting timeliness, SPT site versus HMIS site

Month	Deadline	SPT submitted	HMIS submitted	SPT timely	HMIS timely
Jul-18	5 Aug 2018	3 Aug 2018	6 Aug 2018	Yes	No
Aug-18	5 Sep 2018	5 Sep 2018	5 Sep 2018	Yes	Yes
Sep-18	5 Oct 2018	4 Oct 2018	5 Oct 2018	Yes	Yes
Oct-18	5 Nov 2018	5 Nov 2018	5 Nov 2018	Yes	Yes
Nov-18	5 Dec 2018	5 Dec 2018	2 Dec 2018	Yes	Yes
Dec-18	5 Jan 2019	3 Jan 2019	5 Jan 2019	Yes	Yes
Jan-19	5 Feb 2019	4 Feb 2019	7 Feb 2019	Yes	No
Feb-19	5 Mar 2019	4 Mar 2019	5 Mar 2019	Yes	Yes
Mar-19	5 Apr 2019	3 Apr 2019	5 Apr 2019	Yes	Yes
Apr-19	5 May 2019	3 May 2019	8 May 2019	Yes	No
May-19	5 Jun 2019	3 Jun 2019	5 Jun 2019	Yes	Yes
Jun-19	5 Jul 2019	4 Jul 2019	5 Jul 2019	Yes	Yes
Overall	—	—	—	100%	75%

3.4 Consistency

Cross-checking of individual medical records against DHIS2 found 98.7% (95% CI 98.1–99.3) of SPT-site records to be consistent, with 1.3% inconsistent. At the conventional HMIS site, 93.2% of records were consistent and 6.8% inconsistent when measured against facility registers (Table 4). The small residual inconsistency at the SPT site is most plausibly explained by the additional manual step required to populate DHIS2 from scanned SPT outputs an interface effect discussed below rather than an inaccuracy in SPT capture itself.

Table 4
Record-to-DHIS2 consistency, SPT site versus HMIS site

Consistency status	SPT site n (%)	HMIS site n (%)
Consistent	1481 (98.7)	1398 (93.2)
Inconsistent	19 (1.3)	102 (6.8)

3.5 Administrative time efficiency

Mean first-time data-recording time was 4.0 minutes (SD 1.28; range 2.0–6.5) at the SPT site, compared with 9.9 minutes (SD 1.26; range 8.0–12.4) at the conventional HMIS site a mean difference of 5.9 minutes (95% CI 5.6–6.2; $p < 0.001$) corresponding to a very large standardised effect (Cohen's $d \approx 4.6$). Mean data-processing and reporting time was 2.8 minutes (SD 0.60; range 2.0–4.5) at the SPT site versus 5.8 minutes (SD 1.18; range 4.0–8.5) at the control site a mean difference of 3.0 minutes (95% CI 2.8–3.2; $p < 0.001$; Cohen's $d \approx 3.2$). Notably, the two distributions for data recording did not overlap: the slowest SPT observation (6.5 minutes) was faster than the fastest HMIS observation (8.0 minutes). Taken together, SPT reduced the combined per-encounter administrative time by approximately 8.9 minutes (Tables 5 and 6).

Table 5
Time taken for first-time data recording (minutes)

Facility	Observations	Min	Max	Mean	SD	p-value
Lunga Lunga (SPT)	118	2.0	6.5	4.03	1.28	< 0.001
Vanga (HMIS)	118	8.0	12.4	9.91	1.26	

Mean difference 5.88 minutes (95% CI 5.55–6.21); Cohen's $d \approx 4.63$ (derived from reported group means, SDs and n).

Table 6
Time taken for data processing and reporting (minutes)

Facility	Observations	Min	Max	Mean	SD	p-value
Lunga Lunga (SPT)	118	2.0	4.5	2.83	0.60	< 0.001
Vanga (HMIS)	118	4.0	8.5	5.82	1.18	

Mean difference 3.00 minutes (95% CI 2.76–3.24); Cohen's $d \approx 3.21$ (derived from reported group means, SDs and n).

4. Discussion

This comparative evaluation found that SPT outperformed the conventional paper-based HMIS on three of four data-quality dimensions and roughly halved the administrative time required to record and

process under-five immunisation data, with standardised effect sizes far exceeding conventional thresholds for large effects. The pattern of results is internally coherent: the same structural features of SPT that improve completeness and accuracy also explain its timeliness and efficiency advantages, while the single dimension on which the conventional system held a slight edge is traceable to an identifiable and remediable integration step.

4.1 Data quality in comparative context

The 82.5% completeness recorded under the conventional HMIS at the control site sits within the upper range of figures reported across comparable settings modestly below rates documented in India (88.5%) by Sharma et al. (2016) and in Kenya (86.9%) by Manya and Nielsen (2016) on some indicators, and well above completeness figures reported in Ethiopia (67–78%), Tanzania (68.7%) and Zambia (49.2%) (Kebede et al., 2020; Ouedraogo et al., 2019; Lodge et al., 2020; Moonga, 2016; Taye et al., 2023). The SPT site's 93.5% exceeded all of these comparators. The most credible explanation is structural rather than behavioural: SPT consolidates the multiple disaggregated entry points of the conventional HMIS into a single structured form completed at the moment of service delivery, reducing the omissions that accumulate when totals are reconstructed retrospectively across separate registers. The automated routing of illegible or incomplete entries to a verification officer embeds quality assurance within the capture process rather than deferring it to periodic audits an operational realisation of the continuous, low-threshold review culture that the WHO DQR framework and DHIS2-based quality dashboards seek to institutionalise at district level (WHO, 2017).

The accuracy findings reinforce this interpretation. A verification factor of 1.001 at the SPT site indicates near-perfect concordance between reported and source counts, comparable to the unity values reported for antenatal data in Malawi (O'Hagan et al., 2017), whereas the control site's verification factor of 1.11 reflects the directional under-reporting characteristic of multi-step manual aggregation. By digitising values at the point of capture, SPT removes the arithmetic and transcription errors that propagate across conventional reporting chains. The programmatic significance of a 10% under-count is easily understated: at scale, systematic under-reporting of administered doses depresses measured coverage, distorts denominator-based performance assessment and can misdirect scarce outreach resources toward populations that are in fact already served.

Timeliness showed the sharpest contrast, with the SPT site achieving 100% on-time submission against 75% at the control site. Automated scan-and-process workflows compress the report-generation cycle from days to hours, and timely data is a precondition for timely public-health action, including defaulter tracing and supply alerts. The marginally lower record-to-DHIS2 consistency at the SPT site (98.7%) is the only finding that runs counter to the overall pattern. Because the current implementation still requires a subset of scanned data to be re-keyed into DHIS2 to satisfy national reporting requirements, each additional transfer introduces a potential discrepancy. The implication for programme design is direct: eliminating manual re-entry through SPT–DHIS2 interoperability would be expected to close the residual consistency gap.

4.2 Administrative time efficiency

The time savings observed from 9.9 to 4.0 minutes for recording and from 5.8 to 2.8 minutes for processing are consistent in direction and magnitude with workflow analyses of digitalised vaccination clinics elsewhere in the region and with hybrid digital tools in Uganda and Afghanistan, where session-documentation savings of a similar order have been reported (Chowdhury & Sarker, 2018). The complete separation of the two recording-time distributions in this study strengthens confidence that the difference is a genuine system effect rather than an artefact of sampling variability. The evidence also cautions, however, that such gains are not automatic: where digital tools are layered on top of unchanged workflows, staff may carry a transitional double burden of maintaining legacy paper alongside the new system. The savings at the SPT site are therefore best attributed to the combination of the tool itself and the deliberate process redesign that accompanied it, including a dedicated verification function and a reduction in the number of forms staff must complete.

In a county where facilities routinely serve catchment populations larger than their design capacity, the per-encounter time reduction is most usefully understood not as generating idle capacity but as converting documentation time into clinical time. Aggregated across the daily encounter volume of a busy sub-county hospital, the reclaimed minutes represent a meaningful expansion of effective service-delivery capacity achieved without additional hiring a mechanism through which better data management translates, indirectly but tangibly, into better service delivery.

4.3 Strengths and limitations

Strengths of the study include the use of an independent recounting protocol to verify accuracy, an unobtrusive time-and-motion design that limited observation bias, alignment of the quality dimensions with an internationally recognised assessment framework, and a sample size that exceeded the calculated minimum for both quantitative objectives. Several limitations warrant emphasis. First, the two-site comparison: although the facilities serve comparable catchment populations and deliver the same service package, they were purposively rather than randomly selected, unmeasured facility-level differences cannot be fully excluded, and the design does not support causal attribution at the level a randomised or stepped-wedge study would permit. Second, observations and records within each facility are not statistically independent, and the analysis did not adjust for within-facility clustering; with only one facility per arm, site and system effects cannot be disentangled. Third, although observers were unobtrusive, the possibility of residual Hawthorne effects during timed observations cannot be wholly eliminated. Fourth, the twelve-month window, while adequate for routine reporting metrics, does not capture seasonal or multi-year variation, and the findings derive from a single county and should be generalised cautiously. Multi-site replication across diverse facility types would strengthen external validity.

4.4 Implications

For programme managers and county health authorities, the findings support SPT as a structurally superior approach to immunisation data management in settings where full electronic health records are not yet viable but the limitations of purely paper-based HMIS are acutely felt. The clearest near-term priority is direct SPT–DHIS2 interoperability, which would remove the manual re-entry step responsible for the only quality dimension on which SPT did not lead. Sustaining the time and quality gains at scale will also require attention to the electricity, connectivity and staffing preconditions on which the tool's performance depends. For national digital-health planning, the results illustrate a broader principle consistent with the Immunization Agenda 2030 emphasis on data as a strategic priority: hybrid designs that meet health workers where their current practices are can deliver most of the data-quality benefit of full digitisation at a fraction of its infrastructural demands.

5. Conclusion

In a direct comparison with the conventional paper-based HMIS, Smart Paper Technology produced more complete, more accurate and more timely under-five immunisation data, and approximately halved the administrative time required to record and process that data, with very large standardised effect sizes. The marginal consistency advantage of the conventional system is a solvable integration artefact rather than an intrinsic shortcoming of SPT. These results provide an evidence base for wider adoption of SPT for immunisation reporting in comparable resource-constrained settings, with direct DHIS2 integration identified as the highest-value next step.

Declarations

Ethics approval and consent to participate. The study received approval from the Board of Postgraduate Studies of Jaramogi Oginga Odinga University of Science and Technology, ethical clearance from the JOOUST Ethical Review Committee, a research licence from the National Commission for Science, Technology and Innovation (NACOSTI), and permission from the County Director of Medical Services, Kwale County. Document analysis used de-identified aggregate records.

Consent for publication. Not applicable; no individually identifiable data are presented.

Availability of data and materials. The datasets analysed are available from the corresponding author on reasonable request.

Competing interests. The authors declare that they have no competing interests.

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Authors' contributions. Geoffrey Andrew Otieno conceived and designed the study, collected and analysed the data, and drafted the manuscript. Dr. Jane Owenga and Dr. Daniel Onguru supervised the study and critically revised the manuscript. All authors read and approved the final version.

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References

1. Chowdhury, M., & Sarker, M. (2018). Evaluation of digital data management tools for routine immunisation in low-resource settings. Journal of Health Informatics in Developing Countries.
2. Endriyas, M., Alano, A., Mekonnen, E., Ayele, S., Kelaye, T., Shiferaw, M., et al. (2019). Understanding performance data: health management information system data accuracy in Southern Nations Nationalities and People's Region, Ethiopia. BMC Health Services Research, 19, 175.
3. Kebede, M., Adeba, E., & Chego, M. (2020). Evaluation of quality and use of health management information system in primary health care units of East Wollega Zone, Oromia, Ethiopia. BMC Medical Informatics and Decision Making, 20, 107.
4. Kiberu, V. M., Matovu, J. K., Makumbi, F., Kyozira, C., Mukooyo, E., & Wanyenze, R. K. (2014). Strengthening district-based health reporting through the district health management information software system: the Ugandan experience. BMC Medical Informatics and Decision Making, 14, 40.
5. Lodge, W., Menon, G., Kuchukhidze, S., Jumbam, D. T., Maongezi, S., Alidina, S., et al. (2020). Assessing completeness of patient medical records of surgical and obstetric patients in Northern Tanzania. Global Health Action, 13(1), 1765526.
6. Manya, A., & Nielsen, P. (2016). Reporting practices and data quality in health information systems in developing countries: an exploratory case study in Kenya. Journal of Health Informatics in Developing Countries, 10(1).
7. Moonga, A. (2016). Prevention of mother-to-child transmission of HIV: data quality assessment in selected health facilities of the Southern region of Zambia. University of Zambia.
8. O'Hagan, R., Marx, M. A., Finnegan, K. E., Naphini, P., Ng'ambi, K., Laija, K., et al. (2017). National assessment of data quality and associated systems-level factors in Malawi. Global Health: Science and Practice, 5(3), 367–381.
9. Ouedraogo, M., Kurji, J., Abebe, L., Labonté, R., Morankar, S., Bedru, K. H., et al. (2019). A quality assessment of health management information system (HMIS) data for maternal and child health in Jimma Zone, Ethiopia. PLoS ONE, 14(3), e0213600.
10. Sharma, A., Rana, S. K., Prinja, S., & Kumar, R. (2016). Quality of health management information system for maternal and child health care in Haryana State, India. PLoS ONE, 11(2), e0148449.
11. Smerek, M. M. (2015). Assessing data quality for healthcare systems data used in clinical research (Version 1.0). NIH Collaboratory.
12. Taye, B. K., Gezie, L. D., Atnafu, A., Mengiste, S. A., & Tilahun, B. (2023). Data completeness and consistency in individual medical records of institutional births: a retrospective cross-sectional study from Northwest Ethiopia. BMC Health Services Research, 23, 1189.

13. World Health Organization. (2017). Data quality review: a toolkit for facility data quality assessment. Geneva: WHO.
14. World Health Organization. (2020). Immunization Agenda 2030: a global strategy to leave no one behind. Geneva: WHO.