

Quality of Routine Malaria Surveillance Data in Botswana's Highest-Burden Districts, 2023–2025

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Cite this article as: Khuteletso Bagapi, Galekgatlhe Bailey Balekang, Refilwe Yvonne Karabo, Ibrahim Bayoumy. Quality of Routine Malaria Surveillance Data in Botswana's Highest-Burden Districts, 2023–2025. Texila Int J Acad Res. 2026;13(4).

<https://doi.org/10.21522/TIJAR.2014.13.04.Art002>

Received: 01.09.2026

Accepted: 12.10.2026

Published: 30.10.2026

Article Type: Original Research

Abstract High-quality malaria surveillance is essential for elimination. This study assessed routine malaria surveillance data quality in Botswana's highest-burden districts against WHO-recommended malaria elimination data-quality indicators and examined geographic and temporal variation during 2023–2025. A retrospective data-quality assessment used national Case-Based Surveillance (CBS) records and Integrated Disease Surveillance and Response (IDSR) aggregate counts. Districts were selected using a Pareto approach. Completeness, timeliness, internal consistency and CBS-IDSR agreement were assessed separately. Indicator proportions were summarized with 95% confidence intervals; geographic and annual differences were assessed using Pearson chi-square tests and multivariable logistic regression. The CBS dataset contained 3,393 records with valid analysis years. Okavango, Ngamiland and Chobe contributed 2,729 (80.4%) and formed the primary analytic population. Overall core-variable completeness was 79.5% (2,169/2,729), documented case investigation was 40.9% (1,117/2,729), notification within the day-level 24-hour approximation was 92.5% (2,409/2,603), investigation within 3 days among investigated cases was 58.0% (648/1,117), and internal consistency among evaluable records was 92.7% (825/890). Aggregate CBS-IDSR count agreement across the three districts was 95.7% (2,612 IDSR versus 2,729 CBS cases). Geographic differences were significant for all five case-level indicators ($p < 0.001$). Core completeness, documented investigation and investigation timeliness varied significantly by year, whereas notification timeliness ($p = 0.640$) and internal consistency ($p = 0.311$) did not vary significantly by year. Surveillance performance was heterogeneous across data-quality dimensions, districts and years. Timely notification and aggregate CBS-IDSR agreement were comparatively strong, whereas case-investigation documentation and timeliness remained important weaknesses requiring targeted surveillance strengthening.

Keywords Botswana, Completeness, Data Quality, Internal Consistency, Malaria Surveillance, Timeliness.

Introduction

Botswana's elimination efforts are guided by national and regional commitments, including the Southern African Development Community (SADC) malaria elimination agenda [1], and by the WHO's Global Technical Strategy for Malaria, which emphasizes surveillance as a core intervention and the use of high-quality data for program action [2].

High-quality surveillance is particularly important in elimination settings because incomplete, delayed, or discordant information can obscure transmission, delay case investigation, and weaken the targeting of response [3, 4]. The WHO Malaria Surveillance Assessment Toolkit provides a standardized and adaptable framework for assessing surveillance performance [5]. Under its data-quality subobjective, the toolkit assesses completeness, timeliness, consistency, and concordance. For elimination settings, it recommends case-based data, comparison with other systems that capture malaria cases and deaths, and disaggregation by administrative unit and time period; desk-level data quality assessment uses a suggested minimum of three years of data [5].

Data quality is multidimensional, and reliance on a single indicator can conceal weakness in a critical surveillance function. WHO routine health-information guidance assesses multiple dimensions, including completeness, timeliness, internal consistency, and external consistency [6, 7]. The malaria surveillance toolkit similarly treats completeness, timeliness, consistency, and concordance as distinct dimensions [5]. Studies of surveillance and routine health information systems also show that completeness and timeliness alone may not adequately represent overall system quality and that multidimensional approaches can provide a more informative assessment [5-10].

Accordingly, this study retained the WHO-aligned data-quality dimensions as separate outcomes rather than combining them into a

study-derived composite index. Geographic and temporal variation was evaluated using indicator-specific estimates and inferential statistical comparisons, allowing differences in completeness, timeliness, and consistency to be directly quantified, while CBS-IDSR concordance was examined separately at the district-year level.

Despite Botswana's progress toward elimination, earlier studies documented persistent surveillance and response challenges, including incomplete case notification and limited household-level follow-up [11, 12]. Evidence remains limited on whether recent routine case-based malaria surveillance data in the highest burden districts achieve the quality needed for elimination and whether performance varies by geography and time. Therefore, this study applies the WHO malaria surveillance data-quality framework to a three-year period while retaining the underlying indicators for interpretation [5].

Objectives

1. To assess the performance of routine malaria surveillance data from Botswana's highest malaria burden districts against WHO-recommended malaria elimination data quality indicators for completeness, timeliness, consistency, and concordance during 2023–2025.
2. To assess geographic and temporal variation in malaria surveillance data quality indicators by district and year during 2023–2025.

Novelty and Contribution of the Study

This study applies the 2026 WHO Malaria Surveillance Assessment Toolkit to routine case-based malaria surveillance data in Botswana's highest-burden districts and formally evaluates geographic and temporal differences in indicator-specific data quality. Unlike approaches that collapse heterogeneous dimensions into a single composite, the analysis preserves completeness, timeliness,

consistency, and concordance as distinct surveillance functions and uses inferential statistics to identify where and when performance differs.

Materials and Methods

Study Setting

The study was conducted in Botswana and focused on districts with the highest malaria case burden during the study period. District selection was based on a Pareto approach using routine case-based surveillance (CBS) records from all reporting districts. Districts were ranked in descending order of confirmed malaria case burden, and districts contributing cumulatively at least 80% of reported cases were selected for the detailed data-quality assessment. This approach concentrated the assessment on areas contributing most to the national malaria case burden while applying an objective, prespecified selection criterion.

Study Design and Period

A retrospective cross-sectional data-quality assessment was conducted using routine malaria surveillance records for January 1, 2023, through December 31, 2025. The study uses a three-year analytic window consistent with the WHO toolkit recommendation for desk-level DQA and temporal consistency assessment. Data from 2022 were excluded because identified data-quality concerns could affect the reliability and comparability of surveillance indicators.

Data Sources

The primary source is Botswana malaria case-based surveillance (CBS) data. Integrated Disease Surveillance and Response (IDSR) aggregate case counts are used as a second reporting system for concordance assessment. The analysis is restricted to variables and indicators available in the supplied surveillance datasets and does not claim source-document validation where registers or case-investigation forms were not audited.

Study Population and Sampling

The study comprised confirmed malaria case records reported through the national CBS system during 2023–2025. Following district selection using the prespecified Pareto criterion, all eligible case records from the selected districts were included; therefore, no case-level sampling was performed within the selected districts. Records were eligible if they represented a confirmed malaria case, were reported during the analytic period, had a valid analysis year from 2023 through 2025, and originated from a selected district. Records with a missing or invalid analysis year were excluded because eligibility for the prespecified analytic period could not be established. The final numbers of records screened, excluded, and analyzed, together with the contribution of each selected district, are reported in the Results section.

Data Quality Assessment Framework

The assessment was aligned to the WHO Malaria Surveillance Assessment Toolkit, second edition (2026) [8]. The toolkit identified completeness, timeliness, consistency, and concordance as distinct data-quality dimensions for desk-level assessment. In elimination settings, the WHO recommended the extraction of case-based data and comparison with other systems that captured malaria cases and deaths. Indicators were selected a priori according to their applicability and availability in the Botswana CBS and IDSR datasets.

Completeness

Completeness was assessed using two prespecified indicators. Core-variable completeness was defined as the percentage of eligible cases with non-missing values for all 13 selected WHO-aligned variables available and applicable to all records: patient/system identifier, age, sex, nationality, diagnosis facility, district, symptom-onset date, diagnosis date, case-detection method, parasite species,

notification date, travel history, and final case classification. For cases reporting travel, the travel history item was considered complete only when a travel destination was documented. Documented case investigation was assessed separately from core-variable completeness. Missing investigation status was classified as no documented investigation. Invalid chronological sequences were assessed under temporal consistency rather than as missingness [5].

Timeliness

Timeliness was assessed using two indicators. Notification timeliness was calculated among records with both diagnosis and notification dates and was defined as a diagnosis-to-notification interval of 0-1 calendar days, a day-level approximation of the WHO 24-hour expectation because timestamps were unavailable [5]. Investigation timeliness was assessed among cases documented as investigated and was defined as investigation within 0–3 calendar days of diagnosis, using the current WHO toolkit reference pending confirmation of the Botswana national standard [5]. Missing or invalid investigation dates among cases documented as investigated were classified as not timely. Notification and investigation timeliness were estimated for the three selected districts combined and were additionally disaggregated by district and year to assess geographic and temporal variation.

Concordance

Concordance was assessed by comparing CBS and IDSR confirmed malaria case counts over identical district-year periods. Because record-level linkage was unavailable, the analysis used aggregate count agreement: $100 \times [1 - \text{sum}(|\text{CBS} - \text{IDSR}| / \text{sum} \max(\text{CBS}, \text{IDSR}))]$. For a single district-year, this reduced to $100 \times [1 - |\text{CBS} - \text{IDSR}| / \max(\text{CBS}, \text{IDSR})]$. This symmetric measure was study-derived and was not a WHO-defined score. WHO recommended a comparison of notified

confirmed case numbers between parallel reporting systems in elimination settings [5].

Internal Consistency Checks

Temporal consistency was assessed using WHO-aligned logical chronology checks supported by the line list: symptom onset on or before diagnosis, diagnosis on or before notification, and notification on or before case investigation. The primary consistency outcome required all three checks to be evaluable and to pass. An extended check assessed case investigation on or before focus investigation when both dates were available. Implausible sequences were retained as data-quality failures rather than silently corrected [5]. A separate audit flagged records with at least one temporal inconsistency or a diagnosis year that did not match the recorded analysis year. These audit flags were used to characterize data-quality problems and were silently corrected in the analytic variables.

Assessment of Objectives

Objective 1 was assessed using the individual WHO-aligned indicators for completeness, timeliness, and temporal consistency, together with aggregate CBS–IDSR count agreement. Combined three-district case-level results were presented as numerators, denominators, percentages, and 95% confidence intervals. Objective 2 was assessed by comparing case-level indicators across district and year. The analysis did not use an overall data-quality composite index, thereby avoiding compensation for poor performance in one surveillance function by high performance in another.

Statistical Analysis

Descriptive statistics summarized case counts and data-quality indicators using numerators, denominators, percentages, and 95% confidence intervals. Pearson's chi-square test compared binary case-level indicators across the three selected districts and across years. Multivariable logistic regression models

were fitted separately for core-variable completeness, documented case investigation, notification within 24 hours, investigation within 3 days among investigated cases, and temporal consistency. Each model included district and year as categorical predictors, with Okavango and 2023 as reference categories. Adjusted odds ratios (aORs), 95% confidence intervals, and two-sided p-values were reported; $p < 0.05$ was considered statistically significant. Year was treated primarily as categorical because only three annual periods were available. The CBS-IDSR agreement was assessed descriptively from matched district-year aggregate case counts because record-level

linkage was unavailable. District-by-year interactions and linear year tests were treated as secondary analyses.

Results

Study Population and Pareto Selection

The national CBS dataset contained 3,393 case records, all with valid analysis years from 2023 through 2025. Okavango accounted for 2,074 cases (61.1%), Ngamiland for 342 (10.1%) and Chobe for 313 (9.2%) Together, the three districts contributed 2,279 cases (80.4%) and constituted the primary analytic population (Table 1).

Table 1. Pareto Distribution of Malaria CBS Case Burden by District, BOTSWANA, 2023–2025

District	CBS cases	% of cases	Cumulative %	Selected
Okavango	2,074	61.1	61.1	Yes
Ngamiland	342	10.1	71.2	Yes
Chobe	313	9.2	80.4	Yes
Tutume	145	4.3	84.7	No
Bobirwa	91	2.7	87.4	No
Ghanzi	71	2.1	89.5	No
Boteti	55	1.6	91.1	No
Other districts	302	8.9	100.0	No

WHO-Aligned Data Quality Performance, 2023–2025

Across the three selected districts, core-variable completeness was 79.5% (2,169/2,729; 95% CI 77.9–81.0), documented case investigation was 40.9% (1,117/2,729; 95% CI 39.1–42.8), notification within the day-level 24-hour approximation was 92.5% (2,409/2,603; 95% CI 91.5–93.5), and investigation within 3 days among documented investigations was 58.0% (648/1,117; 95% CI 55.1–60.9). Internal consistency was 92.7%

(825/890; 95% CI 90.8–94.2) among records with all dates required for the primary chronology checks. Aggregate CBS-IDSR count agreement across the three selected districts was 95.7%, with 2,612 IDSR cases compared with 2,729 CBS cases (Table 2). The corresponding evaluable proportions of the 2,729 eligible records were 100.0% for core completeness and documented investigation, 95.4% for notification timeliness, 40.9% for investigation timeliness, and 32.6% for the primary internal consistency outcome (Table 2).

Table 2. Overall WHO-aligned Data-quality Performance across the Three Selected High-burden Districts, Botswana, 2023–2025

Indicator	Combined three districts, n/N (%)	95% CI	Evaluable, n/N (%) of 2,729
Core-variable completeness	2,169/2,729 (79.5%)	77.9–81.0%	2,729/2,729 (100.0%)
Documented case investigation	1,117/2,729 (40.9%)	39.1–42.8%	2,729/2,729 (100.0%)
Notification within 24 h*	2,409/2,603 (92.5%)	91.5–93.5%	2,603/2,729 (95.4%)
Investigation within 3 days†	648/1,117 (58.0%)	55.1–60.9%	1,117/2,729 (40.9%)
Internal consistency‡	825/890 (92.7%)	90.8–94.2%	890/2,729 (32.6%)
CBS-IDSr aggregate count agreement	2,612/2,729 (95.7%)	Not applicable	Not applicable

*Notification within 24 hours was approximated as 0-1 calendar days because timestamps were unavailable.

†Investigation timeliness was assessed among cases documented as investigated.

‡Internal consistency required all three primary chronology checks to be evaluable and passed. CBS-IDSr agreement compared aggregate reported counts (IDSr/CBS) and did not represent individually matched cases; a binomial confidence interval was therefore not applicable. Evaluable n/N (%) reports the number of records contributing to each indicator relative to the 2,729 eligible records.

Individual completeness was high for most demographic and reporting variables. Symptom-onset date was complete in 87.4% of records, parasite species in 91.1%, notification date in 95.4%, and travel history in 98.7%.

Investigation date was recorded in only 35.6% of records. Together with the 40.9% documented-investigation indicator, this identified investigation documentation as the principal completeness weakness (Table 3).

Table 3. Completeness of Individual Malaria Surveillance Variables across the Three Selected High-burden Districts, Botswana, 2023–2025

Variable	Complete, n/N	Completeness (%)
Patient/system identifier	2,729/2,729	100.0
Age	2,729/2,729	100.0
Sex	2,729/2,729	100.0
Nationality	2,723/2,729	99.8
Diagnosis facility	2,717/2,729	99.6
District	2,729/2,729	100.0
Symptom-onset date	2,385/2,729	87.4
Diagnosis date	2,729/2,729	100.0
Case-detection method	2,726/2,729	99.9
Parasite species	2,487/2,729	91.1
Notification date	2,604/2,729	95.4
Travel history*	2,693/2,729	98.7
Final case classification	2,729/2,729	100.0
Investigation date	971/2,729	35.6

*For cases reporting travel, travel history was considered complete only when a travel destination was also documented.

Investigation date was reported separately because investigation is a conditional surveillance process and was not included in the universal core-variable completeness definition.

Internal Consistency

Internal consistency was high among records with sufficient dates for evaluation (Table 4). Among 890 records evaluable for the primary chronology outcome, 825 (92.7%) passed all three primary checks. Component pass rates were 97.8% (2,332/2,385) for symptom onset $\leq$ diagnosis, 99.0% (2,577/2,604) for

diagnosis $\leq$ notification, 94.2% (914/970) for notification $\leq$ case investigation, and 97.4% (339/348) for case investigation $\leq$ focus investigation where evaluable. The substantially smaller denominators for investigation-related checks reflected the availability of the required dates and warrant cautious interpretation (Table 4).

Table 4. Internal Consistency of Malaria Surveillance Records across the Three Selected High-burden Districts, Botswana, 2023–2025

Consistency indicator	Passed, n/N	Pass rate (%)	Evaluable, n/N (%) of 2,729
Primary chronology outcome: all first three checks passed	825/890	92.7	890/2,729 (32.6%)
Symptom onset $\leq$ diagnosis	2,332/2,385	97.8	2,385/2,729 (87.4%)
Diagnosis $\leq$ notification	2,577/2,604	99.0	2,604/2,729 (95.4%)
Notification $\leq$ case investigation	914/970	94.2	970/2,729 (35.5%)
Case investigation $\leq$ focus investigation*	339/348	97.4	348/2,729 (12.8%)

District-year CBS-IDSr agreement varied despite the high combined agreement. Okavango showed agreement of 99.5% in 2023, 100.0% in 2024 and 98.5% in 2025. Agreement in Ngamiland was 96.1%, 69.0% and 77.1%, respectively, and in Chobe was

80.2%, 100.0% and 98.1%. The largest absolute discrepancy occurred in Ngamiland in 2025, when CBS recorded 236 cases and IDSr 182 cases, a difference of 54 cases (29.7% relative to IDSr) (Table 5).

Table 5. CBS-IDSr Aggregate Count Agreement and Discrepancy by District and Year, 2023–2025

Year	District	CBS Confirmed Cases	IDSr Confirmed Cases	Absolute Difference	Aggregate Agreement (%)
2023	Okavango	216	215	1	99.5%
2023	Ngamiland	77	74	3	96.1%
2023	Chobe	111	89	22	80.2%
2024	Okavango	154	154	0	100.0%
2024	Ngamiland	29	20	9	69.0%
2024	Chobe	41	41	0	100.0%
2025	Okavango	1,704	1,679	25	98.5%
2025	Ngamiland	236	182	54	77.1%
2025	Chobe	161	158	3	98.1%

CBS-IDSr agreement was interpreted as an aggregate reporting-system comparison rather than record-level concordance. The study-derived agreement percentage was not used as a WHO pass/fail threshold.

All primary data-quality indicators differed significantly across districts in unadjusted

analyses (all Pearson chi-square $p < 0.001$). Core-variable completeness was 94.6% in

Okavango, 37.7% in Ngamiland and 24.6% in Chobe. Documented case investigation was 43.4%, 15.5% and 52.1%, respectively. Timely notification was 96.9% in Okavango, 77.3% in Ngamiland and 72.6% in Chobe. Among

investigated cases, investigation within 3 days was 68.1% in Okavango, 24.5% in Ngamiland and 12.9% in Chobe. Internal consistency among evaluable records was 94.1%, 100.0% and 63.6%, respectively (Table 6).

Table 6. Geographic Variation in WHO-aligned Case-level Data-quality Indicators and Adjusted District Effects, 2023–2025

Indicator	District	n/N (%)	Pearson p	Adjusted effect vs Okavango	Adjusted p	Evaluable, n/N (%) of district total
Core-variable completeness	Okavango	1,963/2,074 (94.6)	<0.001	Reference	-	2,074/2,074 (100.0%)
	Ngamiland	129/342 (37.7)		aOR 0.034 (0.025–0.045)	<0.001	342/342 (100.0%)
	Chobe	77/313 (24.6)		aOR 0.017 (0.012–0.025)	<0.001	313/313 (100.0%)
Documented case investigation	Okavango	901/2,074 (43.4)	<0.001	Reference	-	2,074/2,074 (100.0%)
	Ngamiland	53/342 (15.5)		aOR 0.127 (0.089–0.182)	<0.001	342/342 (100.0%)
	Chobe	163/313 (52.1)		aOR 0.784 (0.593–1.036)	0.087	313/313 (100.0%)
Notification within 24 h*	Okavango	2,009/2,073 (96.9)	<0.001	Reference	-	2,073/2,074 (100.0%)
	Ngamiland	249/322 (77.3)		aOR 0.104 (0.072–0.150)	<0.001	322/342 (94.2%)
	Chobe	151/208 (72.6)		aOR 0.084 (0.056–0.125)	<0.001	208/313 (66.5%)
Investigation within 3 days†	Okavango	614/901 (68.1)	<0.001	Reference	-	901/2,074 (43.4%)
	Ngamiland	13/53 (24.5)		aOR 0.106 (0.054–0.207)	<0.001	53/342 (15.5%)
	Chobe	21/163 (12.9)		aOR 0.060 (0.036–0.098)	<0.001	163/313 (52.1%)
Internal consistency‡	Okavango	781/830 (94.1)	<0.001	Reference	-	830/2,074 (40.0%)
	Ngamiland	16/16 (100.0)		Not estimable§	-	16/342 (4.7%)
	Chobe	28/44 (63.6)		aOR 0.083 (0.040–0.174)	<0.001	44/313 (14.1%)

*Notification within 24 hours was a day-level approximation based on 0-1 calendar days from diagnosis to notification. †Investigation timeliness was assessed among cases documented as investigated. Okavango was the reference district.

Temporal Variation

Core-variable completeness increased from 56.9% in 2023 to 86.6% in 2024 and was 83.1% in 2025 ($p < 0.001$). Documented case investigation increased from 65.6% in 2023 to 85.3% in 2024 but fell to 31.5% in 2025 ($p < 0.001$). Timely notification remained high

and did not differ significantly by year: 93.0% in 2023, 91.0% in 2024 and 92.7% in 2025 ($p = 0.640$). Among investigated cases, investigation within 3 days was 61.5% in 2023, 72.3% in 2024 and 52.5% in 2025 ($p < 0.001$). Internal consistency was 93.5%, 94.9% and 91.6%, respectively ($p = 0.311$) (Table 7).

Table 7. Temporal Variation in WHO-aligned Case-level Data-quality Indicators and Adjusted Year Effects, 2023–2025

Indicator	Year	n/N (%)	Pearson p	Adjusted effect vs 2023	Adjusted p	Evaluable, n/N (%) of year total
Core-variable completeness	2023	230/404 (56.9)	<0.001	Reference	-	404/404 (100.0%)
	2024	194/224 (86.6)		aOR 7.06 (4.09–12.18)	<0.001	224/224 (100.0%)
	2025	1,745/2,101 (83.1)		aOR 1.93 (1.39–2.67)	<0.001	2,101/2,101 (100.0%)
Documented case investigation	2023	265/404 (65.6)	<0.001	Reference	-	404/404 (100.0%)
	2024	191/224 (85.3)		aOR 2.97 (1.89–4.68)	<0.001	224/224 (100.0%)
	2025	661/2,101 (31.5)		aOR 0.172 (0.133–0.222)	<0.001	2,101/2,101 (100.0%)
Notification within 24 h*	2023	278/299 (93.0)	0.640	Reference	-	299/404 (74.0%)
	2024	202/222 (91.0)		aOR 0.872 (0.436–1.743)	0.699	222/224 (99.1%)
	2025	1,929/2,082 (92.7)		aOR 0.728 (0.438–1.212)	0.222	2,082/2,101 (99.1%)
Investigation within 3 days†	2023	163/265 (61.5)	<0.001	Reference	-	265/404 (65.6%)
	2024	138/191 (72.3)		aOR 1.55 (0.97–2.48)	0.069	191/224 (85.3%)
	2025	347/661 (52.5)		aOR 0.481 (0.342–0.676)	<0.001	661/2,101 (31.5%)
Internal consistency‡	2023	188/201 (93.5)	0.311	Reference	-	201/404 (49.8%)
	2024	167/176 (94.9)		aOR 2.13 (0.82–5.54)	0.119	176/224 (78.6%)
	2025	470/513 (91.6)		aOR 0.781 (0.401–1.519)	0.466	513/2,101 (24.4%)

*The focus-investigation chronology check was an extended consistency check and was evaluated only where both case-investigation and focus-investigation dates were available. The primary overall consistency outcome required the first three checks to be evaluable and passed. Ngamiland had complete prediction for the primary outcome (16/16 evaluable records passed), so its adjusted district effect was not estimable by standard logistic regression.

*Notification within 24 hours was a day-level approximation based on 0-1 calendar days.

†Investigation timeliness was assessed among cases documented as investigated. The year 2023 was the reference category.

Geographic and Temporal Variation in Internal Consistency

Internal consistency varied substantially by district but did not vary significantly by year. Overall, 781/830 (94.1%) evaluable records in Okavango, 16/16 (100.0%) in Ngamiland, and 28/44 (63.6%) in Chobe passed all three primary chronology checks (Pearson chi-square $p < 0.001$). Across years, 188/201 (93.5%) records passed in 2023, 167/176 (94.9%) in

2024, and 470/513 (91.6%) in 2025 (Pearson chi-square $p = 0.311$). The district-by-year interaction was not statistically significant ($p = 0.889$). Because all 16 evaluable Ngamiland records passed the primary consistency outcome, its district-specific adjusted odds ratio was not estimable using standard logistic regression. The small and selective district-year denominators warrant cautious interpretation (Table 8).

Table 8. Primary Internal Consistency Outcome by District and Year, Botswana, 2023–2025

District	Year	Passed, n/N	Pass rate (%)	Evaluable, n/N (%) of eligible records
Okavango	2023	178/189	94.2	189/216 (87.5%)
	2024	146/150	97.3	150/154 (97.4%)
	2025	457/491	93.1	491/1,704 (28.8%)
	Overall	781/830	94.1	830/2,074 (40.0%)
Ngamiland	2023	6/6	100.0	6/77 (7.8%)
	2024	6/6	100.0	6/29 (20.7%)
	2025	4/4	100.0	4/236 (1.7%)
	Overall	16/16	100.0	16/342 (4.7%)
Chobe	2023	4/6	66.7	6/111 (5.4%)
	2024	15/20	75.0	20/41 (48.8%)
	2025	9/18	50.0	18/161 (11.2%)
	Overall	28/44	63.6	44/313 (14.1%)
All districts	2023	188/201	93.5	201/404 (49.8%)
	2024	167/176	94.9	176/224 (78.6%)
	2025	470/513	91.6	513/2,101 (24.4%)
	Overall	825/890	92.7	890/2,729 (32.6%)

Statistical tests: overall district comparison, Pearson chi-square $p < 0.001$; overall year comparison, Pearson chi-square $p = 0.311$; district-by-year interaction from logistic regression, $p = 0.889$. Ngamiland adjusted district effect was not estimable because of complete prediction (16/16 passed).

Discussion

This study found substantial heterogeneity in malaria surveillance data quality across dimensions, districts, and years in Botswana's three highest-burden districts. For Objective 1, notification timeliness (92.5%), internal consistency among evaluable records (92.7%), and aggregate CBS-IDS count agreement (95.7%) were comparatively strong. In contrast, only 40.9% of cases had a documented investigation, and 58.0% of documented

investigations occurred within 3 days. Core-variable completeness was 79.5%. Preserving the WHO-aligned indicators separately made these contrasting surveillance functions visible rather than allowing strong performance in one dimension to offset poor performance in another [5, 6].

The most important operational weakness was case investigation. Although most demographic and reporting variables were highly complete, investigation dates were documented for only 35.6% of records, and

documented investigation was present for 40.9%. Notification was timely in 92.5% of evaluable cases, whereas only 58.0% of documented investigations occurred within three days. Internal consistency was high among evaluable records, but only 890/2,729 (32.6%) records were evaluable for the primary chronology outcome, emphasizing the need to interpret the 92.7% pass rate alongside its denominator. In an elimination setting, rapid notification alone is insufficient if cases are not subsequently investigated and classified in time to support interruption of transmission. Reactive case detection and investigation have been central to elimination surveillance in Eswatini and other low-transmission settings [18-21]. This is also consistent with the regional SADC elimination framework, in which timely, case-based surveillance and coordinated cross-border response are essential as transmission becomes increasingly focal [1].

For Objective 2, geographic differences were large and persisted after adjustment for year. Okavango had substantially higher core-variable completeness and timeliness than Ngamiland and Chobe. Compared with Okavango, adjusted odds of core completeness, timely notification, and timely investigation were markedly lower in both Ngamiland and Chobe. Ngamiland also had lower adjusted odds of documented investigation, whereas Chobe did not differ significantly from Okavango for that outcome. Internal consistency also differed by district among evaluable records: 94.1% in Okavango, 100.0% in Ngamiland, and 63.6% in Chobe ($p < 0.001$). However, the Ngamiland estimate was based on only 16 evaluable records, and its adjusted district effect was not estimable because all 16 passed the primary consistency outcome. Earlier Botswana studies documented the geographic concentration of malaria burden and persistent surveillance and response challenges during the country's progression toward elimination [14-16]. Comparable subnational

heterogeneity has also been reported in Madagascar [22].

Temporal patterns were heterogeneous. Core-variable completeness improved from 56.9% in 2023 to 86.6% in 2024 and remained relatively high at 83.1% in 2025. Documented case investigation increased from 65.6% in 2023 to 85.3% in 2024 before falling sharply to 31.5% in 2025, and investigation timeliness also declined to 52.5% in 2025. In contrast, notification timeliness did not differ significantly across years ($p = 0.640$), and internal consistency among evaluable records also showed no significant annual difference (93.5% in 2023, 94.9% in 2024, and 91.6% in 2025; $p = 0.311$). The district-by-year interaction for internal consistency was also not statistically significant ($p = 0.889$). Because only three years were analyzed and the evaluable proportions for consistency varied by year, these findings represent year-to-year variation rather than evidence of a stable long-term trend. Temporal instability in malaria surveillance performance has also been documented elsewhere in Africa [23].

The observed district and year differences should not be attributed to specific operational causes without supporting program evidence. The Botswana literature has identified broader program challenges, including surveillance limitations, vector-control implementation gaps, and resource constraints [16, 17]. The recent malaria upsurge also prompted intensified surveillance and response activities [24].

Strengths include the use of routine operational surveillance data, a standardized WHO-aligned framework, explicit geographic and annual disaggregation, indicator-specific inferential analyses, and transparent reporting of the records evaluable for each indicator. The use of multivariable logistic regression allowed district differences to be estimated while accounting for year, and temporal differences to be estimated while accounting for district.

Several limitations should be considered. First, data from 2022 were excluded because of identified data-quality concerns; consequently, temporal analyses were restricted to three years and could not establish longer-term trends. Second, the available data contained calendar dates rather than timestamps, so notification within 24 hours was approximated as 0-1 calendar days. Third, internal consistency could only be assessed among records with all dates required for the primary checks, producing a smaller and potentially selective denominator; the evaluable proportion was 32.6% overall and varied substantially by district and year. Complete prediction in Ngamiland also prevented estimation of its standard logistic-regression district effect for consistency. Fourth, CBS-IDSr agreement was based on aggregate district-year counts rather than record-level linkage and therefore did not demonstrate that the same individual cases were captured in both systems. Fifth, the primary DQA focused on districts accounting for 80.4% of CBS records and may not represent lower-burden districts. Finally, this desk-level assessment did not independently verify accuracy against source registers or case-investigation forms.

Recommendations

The findings support prioritizing case-investigation completion and timeliness, particularly in Ngamiland and Chobe; routine reconciliation of CBS and IDSr; automated validation of chronological date sequences; district-level DQA dashboards that display completeness, timeliness, concordance, and consistency; and annual review of domain-specific performance. The large district differences also support targeted supervision rather than relying only on national aggregate indicators. These actions are consistent with WHO approaches to malaria surveillance assessment and routine data-quality assurance [4-6] and with evidence on interventions to

improve routine health information system data quality and use [11-13].

Conclusion

During 2023–2025, malaria surveillance data quality in Botswana's three highest-burden districts showed a comparatively strong performance for notification timeliness, temporal consistency among evaluable records, and aggregate CBS-IDSr count agreement, but significant weaknesses in core-variable completeness, documented case investigation, and investigation timeliness. Performance varied substantially by district, with lower adjusted odds of several quality outcomes in Ngamiland and Chobe than in Okavango. Temporal changes were also heterogeneous: core-variable completeness improved, notification timeliness remained statistically stable, and case-investigation performance deteriorated in 2025. Routine monitoring should therefore retain the WHO-aligned indicators separately and prioritize district-specific gaps in investigation completion, investigation timeliness, and data completeness. Strengthening these functions is consistent with WHO elimination surveillance expectations and the regional SADC objective of maintaining sensitive, timely surveillance capable of detecting and responding to residual and imported transmission [1, 5, 20].

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgements

The authors acknowledge the Botswana National Malaria Programme for facilitating access to the data used in this study and thank Dr Phenyio Lekone and Mr Hari Krishnan for their guidance and support.

Ethical Approval

This study was ethically approved by the Ministry of Health -Botswana IRB on the 24th April, 2026 (Ref Number; HPRD:6/14/1) as well as the Ministry of Local Government and

Traditional Affairs Research Unit (Ref Number CMLGTA 1/15/4/I/26) on 09th, July, 2026). Ethical approval was given to use the routine National Malaria Programme data.

Author Contributions

The listed Authors have made significant contributions to the study and have gladly approved this final manuscript for its submission.

- **Khuteletso Bagapi:** Conceptualization of the study, study design, data request and ethical approval process, data analysis, manuscript drafting, and final revision.
- **Ibrahim Bayoumy:** Supervision of development of research proposal and preparation for ethical clearance.
- **Galekgatlhe Bailey Balekang:** Guided the preparation for statistical analysis,

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review of results, interpretation of results, manuscript proofreading, and contribution to final draft preparation.

- **Refilwe Yvonne Karabo:** Manuscript proofreading, and contribution to final draft preparation.

Data Availability

The data set used for this study has been approved for this study's academic purposes only and cannot be shared with third parties, however interested parties are permitted to make a separate request application to the Botswana Ministry of Health.

Funding

This study was self-sponsored by the lead author(student), since the author received no external funding for this study.

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