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Information Quality and Epidemiological Surveillance Governance in Brazil: Territorial Disparities and Evidence from Severe Acute Respiratory Syndrome Records (2016–2025)

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ABSTRACT: Epidemiological surveillance depends on reliable information, yet incomplete, inconsistent, and documentarily noncompliant records may compromise public health decisions and obscure territorial inequalities. This study aimed to assess the longitudinal quality of severe acute respiratory syndrome surveillance records in Brazil from 2016 to 2025, examining their implications for information reliability and public governance. A retrospective observational study analyzed 4,577,627 publicly available records from Sinan Web Influenza and SIVEP-Gripe. Informative completeness, documentary conformance, internal consistency, and notification timeliness were evaluated using version-specific eligibility criteria, 20 consistency rules, territorial comparisons, and fixed-effects regression models. Overall informative completeness was 88.91%, declining to 87.32% in 2022 before recovering to 92.98% in 2025. Educational attainment and chest radiography accounted for 37.91% of information gaps. Approximately 711,323 inconsistencies and 1,361,211 documentary nonconformities were identified across their respective evaluation opportunities. Notification delays peaked in 2021, while substantial regional disparities persisted. Regression models revealed no statistically significant associations between notification volume and quality indicators. These findings demonstrate that formal data completion does not necessarily ensure analytical usefulness or documentary coherence, highlighting limitations in surveillance information reliability. Although secondary data and documentary changes restrict causal interpretation, the multidimensional approach provides evidence for differentiated quality monitoring. Strengthening surveillance governance requires greater attention to informational usability, territorial disparities, and systematic validation to support transparent and equitable public health decision-making.

KEYWORDS: Data Completeness. Public Health Informatics. Administrative Capacity. Epidemiological Monitoring. Health Information Systems.

1. INTRODUCTION

Reliable epidemiological surveillance depends not only on the volume of information collected but also on its accuracy, interpretability, and suitability for public health decision-making. Information systems support the identification of health threats, resource allocation, and the evaluation of public policies. Yet their institutional relevance becomes questionable when formally completed records contain missing, contradictory, or analytically unusable information. German et al. (2001) identify data quality and timeliness as essential attributes of surveillance systems, while Kahn et al. (2016) distinguish completeness, conformance, and plausibility as complementary dimensions of data quality. Such distinctions challenge the assumption that extensive databases necessarily produce trustworthy evidence.

From a governance perspective, information quality also concerns the institutional capacity to establish recording standards, maintain comparable data, and ensure accountability in their use. The World Health Organization (2023) emphasizes systematic quality assessment through documented indicators and verification procedures. Its data governance principles further associate reliable information with transparency, responsible data management, and evidence-informed decisions (World Health Organization, n.d.). Consequently, weaknesses in completeness, internal consistency, or notification timeliness should not be regarded merely as technical imperfections. They may constrain the visibility of population needs, undermine surveillance monitoring, and compromise the informational foundations of public administration.

Brazilian surveillance of severe acute respiratory syndrome (SRAG) has undergone substantial operational transformations. Records were managed through Sinan Web Influenza until 2018, with SIVEP-Gripe becoming the official system in 2019. Subsequent changes in notification forms, coding structures, and epidemiological demands, particularly during the COVID-19

pandemic, introduced additional challenges for longitudinal assessment (Ministério da Saúde, n.d.). These transformations raise a fundamental methodological question: to what extent do variations in surveillance indicators reflect changes in record quality rather than differences in reporting requirements, data structures, or the populations being monitored?

Previous research has identified persistent weaknesses in respiratory surveillance information. Ribas et al. (2022) documented limitations in the completeness of Brazilian SRAG notifications during 2020. Examining a longer period, Leandro et al. (2025) identified territorial disparities and deterioration in completeness during the pandemic. Espírito Santo and Boing (2026) also reported substantial heterogeneity in completeness and timeliness among COVID-19-related SRAG records. International evidence reinforces these concerns: Simpson et al. (2021) demonstrated variations in influenza surveillance data completeness across the Americas, whereas Marques et al. (2025) identified differences in completeness and other surveillance attributes across 27 European countries.

Despite these contributions, important analytical limitations remain. Assessments centered on isolated indicators may overlook the distinction between missing information, documentary nonconformance, logical inconsistencies, and reporting delays. Furthermore, changes in surveillance instruments complicate historical comparisons, while territorial disparities raise questions about the informational conditions under which public health decisions are made. Addressing these issues requires an integrated assessment that preserves the specificity of each quality dimension without attributing observed differences to institutional mechanisms that have not been directly measured.

Understanding whether surveillance records remain sufficiently informative, internally coherent, and timely across changing institutional and epidemiological contexts is essential for assessing their usefulness in public governance. Although previous Brazilian studies have examined completeness and timeliness, a longitudinal approach integrating documentary requirements, conditional consistency rules, and territorial differences offers an opportunity to extend current knowledge (Kahn et al., 2016; Leandro et al., 2025; Espírito Santo & Boing, 2026).

Accordingly, this study examines how the quality of Brazilian SRAG surveillance records varied between 2016 and 2025 and what these variations imply for the reliability of epidemiological information and surveillance governance. Drawing on 4,577,627 records, it evaluates informative completeness, documented requirement conformance, internal consistency, and notification timeliness, considering changes in reporting systems, temporal patterns, and territorial heterogeneity. By distinguishing measurable data quality problems from their potential institutional implications, the study seeks to contribute both to methodological debates on surveillance assessment and to critical discussions about the production and use of public health information.

2 METHODS

2.1 Study Design, Data Sources, and Analytical Population

This retrospective observational study assessed the longitudinal quality of routinely collected epidemiological surveillance records in Brazil from 2016 to 2025. The analysis included 4,577,627 records of severe acute respiratory syndrome (SRAG) obtained from publicly accessible, anonymized databases maintained by the Brazilian Ministry of Health. Reporting was guided by the applicable recommendations of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement and the REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) extension (von Elm et al., 2007; Benchimol et al., 2015).

Surveillance records for 2016 to 2018 originated from the historical Sinan Web Influenza databases, whereas records from 2019 onward were obtained from SIVEP-Gripe. Annual counts were 54,380 in 2016, 29,551 in 2017, 47,756 in 2018, 48,941 in 2019, 1,206,920 in 2020, 1,745,672 in 2021, 560,577 in 2022, 279,453 in 2023, 267,986 in 2024, and 336,391 in 2025. The datasets and corresponding notification forms and data dictionaries were obtained from the Brazilian Unified Health System Open Data Portal (Ministério da Saúde, n.d.).

Database extracts for 2019 to 2024 were identified with the reference date of March 23, 2026, while the 2025 extract was dated September 14, 2026. Because public surveillance databases may undergo retrospective corrections and updates, the 2025 dataset was treated as a dated analytical snapshot rather than an immutable representation of all notifications for that year. The unit of analysis was the individual surveillance record as released in the source database, not a deduplicated patient or clinical episode.

2.2 Data Harmonization and Longitudinal Comparability

Comparability across the study period required explicit consideration of changes in surveillance systems, notification forms, variable names, coding domains, and documentary requirements. The Ministry of Health identifies Sinan Web Influenza as the official SRAG reporting system through 2018 and SIVEP-Gripe as its successor from 2019 onward (Ministério da Saúde, n.d.). Consequently, equivalent field names or apparently similar categories were not assumed to have identical operational meanings across all years. This approach follows the multidimensional understanding of data quality proposed by Kahn et al. (2016) and the

emphasis on documented quality assessment procedures established by the World Health Organization (2023).

Harmonization preserved original field values while establishing analytical correspondence between variables with equivalent meanings. Structural availability, documentary applicability, coding validity, and eligibility for each quality assessment were determined according to the relevant version of the notification form. Fields absent from a particular version were excluded from the corresponding evaluation opportunities rather than classified as incomplete. Conditional requirements were activated only when the necessary trigger information was available and satisfied the documented conditions. Particular attention was given to pregnancy, education, age representation, specimen collection, diagnostic classification, and dates associated with hospitalization or case closure.

The principal longitudinal panel comprised 25 variables covering notification and demographic information, clinical manifestations, hospitalization, diagnostic procedures, classification, and outcomes. Although this harmonized panel allowed assessment across ten years, it did not imply complete measurement invariance: differences in documentary requirements and the composition of eligible records remained relevant when interpreting temporal changes (Kahn et al., 2016; World Health Organization, 2023). Table 1 summarizes the principal harmonization domains and eligibility conditions used in the analysis.

Table 1. Longitudinal Harmonization Matrix and Documentary Eligibility Criteria for SRAG Surveillance Variables, Brazil, 2016 to 2025

Variable group and fields	2016 to 2018	2019 to 2025	Harmonization and eligibility criteria
Notification and residence: notification date, symptom onset, notification state, residence state	Sinan Web Influenza	SIVEP-Gripe	Corresponding variables assessed across versions; dates checked for validity; residence state evaluated separately for national completeness and territorial assignment
Sociodemographic characteristics: sex, race/skin color, education, pregnancy	Historical coding and applicability rules	SIVEP-Gripe coding and applicability rules	Version-specific category domains; pregnancy evaluated according to sex and age; education evaluated according to documented age applicability
Clinical manifestations: fever, cough, dyspnea, respiratory discomfort, oxygen saturation below 95%	Historical form fields	Modern form fields	Structural availability and documented response categories checked by version; blank, unknown, and inapplicable states differentiated
Hospital care: hospitalization, admission date, ICU admission, ICU entry date, ventilatory support	Historical hospitalization and ICU fields	SIVEP-Gripe hospitalization and ICU fields	Conditional date eligibility; temporal checks differentiated according to fields available in each version
Diagnostic procedures: specimen collection, collection date, chest radiography result	Historical laboratory and imaging categories	Revised laboratory and imaging categories	Version-specific specimen codes and conditional collection-date requirements; meaningful categories such as examination not performed distinguished from missing information
Classification and outcome: final classification, confirmation criterion, outcome, closure date	Historical classification and closure rules	Revised classification and closure rules	Documentary requirements and logical compatibility evaluated according to the applicable form and reporting period

Note. ICU = intensive care unit; SRAG = severe acute respiratory syndrome. The matrix summarizes the harmonization framework applied to the 25 longitudinal fields. Structural presence does not imply that every field was mandatory or evaluable for every record.

Source: Authors' organization based on Brazilian Ministry of Health notification forms, data dictionaries, and the analytical protocol (Ministério da Saúde, n.d.).

2.3 Data Quality Dimensions, Eligibility Criteria, and Indicators

Four complementary dimensions were examined: informative completeness, documentary conformance, internal consistency, and notification timeliness. Their operational separation was intended to avoid equating syntactically populated fields with meaningful, logically coherent, or documentarily compliant information. This distinction is consistent with Kahn et al. (2016), German et al. (2001), and the World Health Organization (2023).

Informative completeness represented the proportion of eligible field-level observations containing substantively usable

information. Values were classified as fully informative, partially informative, unknown or ignored, blank, invalid, or structurally absent or inapplicable. Only fully informative values contributed to the numerator, while eligibility depended on structural existence and field applicability. Syntactic completeness, calculated separately, captured the presence of formally populated content, including categories that were not necessarily informative. Residence-state completeness required particular caution: records lacking valid state information were distinguished from records eligible for territorial stratification, preventing geographic assignability from being interpreted as evidence of perfect national completeness.

Documentary conformance assessed whether recorded values satisfied version-specific requirements concerning mandatory fields, conditional obligations, applicable domains, and expected system-generated information. Strict conformance assessment was restricted to requirements classified as mandatory or key in the documentary protocol. Unconditionally mandatory fields contributed all records within their applicable period to the denominator, including records with missing or invalid values.

Conditional requirements contributed an evaluation opportunity only when their documentary trigger was satisfied. Internal consistency was evaluated through 20 logical, demographic, classification, and temporal rules, each with its own eligibility conditions and documentary period. A rule-level opportunity represented one record in which the relevant verification could be performed; the aggregate inconsistency rate was calculated by dividing total detected violations by total eligible rule opportunities. Notification timeliness was defined as the interval in calendar days between symptom onset and notification, summarized using medians and interquartile ranges.

Table 2. Operational Definitions, Eligibility Criteria, and Denominators of Data Quality Indicators

Dimension or verification	Operational criterion	Eligible denominator
Informative completeness	Fully informative values divided by applicable field-level opportunities	106,544,628
Syntactic completeness	Formally populated values divided by applicable field-level opportunities	Field-specific opportunities
Strict documentary nonconformance	Violations of mandatory or key documentary requirements	68,808,095
Internal inconsistency	Violations detected by 20 predefined conditional rules	59,939,228
Notification timeliness	Days between symptom onset and notification	Records with evaluable date pairs
C1. Symptom onset and notification	Symptom onset must not follow notification	4,577,627
C2. Birth and symptom onset	Birth date must not follow symptom onset	4,573,312
C3. Hospital admission and symptom onset	Hospital admission must satisfy the documented temporal condition	4,067,128
C4. ICU entry and admission, historical records	ICU entry must not precede hospital admission	44,243
C5. ICU entry and symptom onset, modern records	ICU entry must not precede symptom onset	1,232,101
C6. ICU discharge and entry	ICU discharge must not precede ICU entry	765,210
C7. Specimen collection and symptom onset	Collection must not precede symptom onset	4,201,906
C8. PCR result and collection	Laboratory result date must not precede specimen collection	3,110,812
C9. Antiviral treatment and symptom onset, historical records	Antiviral date must satisfy the temporal condition	85,443
C10. Outcome date and symptom onset, historical records	Outcome-related date must not precede symptom onset	114,091
C11. Outcome date and symptom onset, modern records	Outcome date must not precede symptom onset	3,763,264
C12. Case closure and notification	Closure must not precede notification	4,276,220
C13. Categorical domains	Nonempty categorical values must conform to applicable documented domains	4,577,627
C14. Confirmation criterion and final classification	Compatibility under the specified modern classification condition	1,952,129

C15. Classification after documentary revision	Compatibility of classification and criterion under revised conditions	138,917
C16. Pregnancy, sex, and age	Pregnancy applicability must agree with sex and age	4,576,936
C17. Education and age	Education applicability must agree with age	4,548,344
C18. Age-unit validity	Recorded age unit must belong to the permitted domain	4,445,940
C19. Age value and unit	Recorded age and unit must constitute an admissible combination	4,445,940
C20. Recorded and date-derived age	Recorded age must agree with age derived from valid dates	4,442,038

Note. Denominators refer to the analytical protocol reported in the original study, not to independent patients. The 20 rule denominators sum to 59,939,228 evaluation opportunities. C3, C5, C8, and C11 follow modern-record eligibility conditions; C4, C9, and C10 concern historical records; C14 applies from 2020, C15 from 2022, and C18 to C20 from 2019. Rule C17 treats children younger than seven years as requiring the documented not-applicable category and excludes the exact age of seven from automatic adjudication. Rates from different dimensions are not directly additive.
Source: Authors' analytical protocol and database audit.

2.4 Temporal and Territorial Analysis

Annual indicators were calculated for Brazil as a whole, its five geographic macroregions, and the 27 federative units (states and the Federal District). Territorial classification was based on state of residence rather than state of notification, thereby avoiding the assumption that the reporting location necessarily represented the place of residence, exposure, or infection. This distinction is especially relevant when surveillance records are used to interpret territorial differences in health information systems (Leandro et al., 2025; World Health Organization, 2023).

Geographic validation accepted only codes corresponding to the 27 federative units. Records without a valid residence-state code were retained in national estimates and assigned to an unclassified territorial category, without imputation or redistribution. They were excluded only from analyses requiring state or regional identification. The resulting territorial panel comprised 270 state-year observations. Municipality-level validity was not adjudicated because a versioned official municipal reference had not been incorporated into the original analytical protocol. Consequently, territorial indicators described record quality by state of residence, without establishing the municipality of infection or the organizational source of recording deficiencies.

Longitudinal analyses examined annual completeness, inconsistency, and notification delays, while regional comparisons described the distribution of these measures across territories. Temporal interpretation considered changes in reporting instruments, documentary eligibility, and record composition, particularly across the periods preceding, encompassing, and following the most intensive phase of the COVID-19 pandemic. Observed differences were treated descriptively and were not interpreted as direct measures of institutional performance.

2.5 Statistical Models and Sensitivity Analyses

Associations between annual notification volume and information quality were examined using the panel of 270 state-year observations. Notification volume was transformed using a base-2 logarithm, allowing coefficients to represent the estimated change in each outcome associated with a doubling of notifications. Weighted least squares (WLS) models included state and year fixed effects, with cluster-robust standard errors at the state level. This specification accounted for time-invariant differences between federative units and common annual variation, although it could not eliminate unmeasured time-varying confounding (Cameron & Miller, 2015).

Three outcomes were analyzed: informative completeness in percentage points, inconsistency per eligible rule opportunity in percentage points, and median notification delay in days. Weights reflected the natural denominator of each outcome within each state-year observation: eligible completeness opportunities, rule-level consistency opportunities, and records with evaluable notification intervals, respectively. Weights were normalized by their means, preserving the relative weighting structure and WLS coefficient estimates. Results were expressed as regression coefficients, cluster-robust standard errors, 95% confidence intervals, p values, and coefficients of determination. Statistical associations were interpreted without causal attribution.

Robustness was examined through comparisons between informative and syntactic completeness, inconsistency rates and the proportion of records containing at least one violation, and notification intervals with and without negative values. Additional analyses compared weighted and unweighted ordinary least squares models, excluded the 2025 observations, and repeated model estimation after successively removing each of the 27 federative units. The original protocol also examined extreme recorded ages and independently reassessed the three most frequent consistency violations. These procedures were intended to identify sensitivity to outcome definitions, weighting choices, territorial influence, and documentary interpretation, consistent with

transparent observational reporting (von Elm et al., 2007; Benchimol et al., 2015).

Because the number and eligibility of consistency rules varied across reporting periods, an additional fixed-composition analysis was restricted to the two rules evaluable throughout 2016 to 2025: pregnancy applicability according to sex and age, and education applicability according to age. Annual inconsistency rates were calculated using the sum of violations divided by the combined eligible opportunities for these two rules. This procedure improved the comparability of the selected consistency indicators without establishing invariance of the entire 20-rule framework. No composite data quality score was constructed.

2.6 Data Integrity, Ethical Considerations, and Reproducibility

Data integrity procedures included reconciliation of annual record counts, verification of analytical keys, inspection of variable types and coding domains, date parsing validation, and comparison between national and territorially aggregated results. Six exact duplicate rows were identified in the historical databases, comprising one in 2016, four in 2017, and one in 2018. They were retained to preserve correspondence with the released source records, without inferring that these rows necessarily represented duplicate patients. An ISO-format date interpretation problem was identified and corrected during the original database audit, followed by reconstruction and revalidation of the affected temporal analyses.

Independent verification focused on pregnancy applicability, education applicability, and consistency between recorded age and age derived from valid dates. The three rules were recalculated directly from the underlying analytical fields, independently of the previously generated outcome indicators, and compared at the record level. Conditional classification denominators were also reviewed to prevent eligibility from being determined by the inconsistency itself. These procedures were designed to assess computational integrity while recognizing that agreement between independent calculations does not, by itself, establish the clinical validity or documentary appropriateness of every rule (Kahn et al., 2016; World Health Organization, 2023).

Ethical considerations reflected the exclusive use of publicly released, anonymized secondary information, without access to names, personal identification numbers, or individual addresses. Brazilian National Health Council Resolution No. 510/2016, Article 1, sole paragraph, addresses research using publicly accessible information and publicly available aggregated databases; its applicability must be considered according to the characteristics of the study and the Brazilian research ethics framework (Conselho Nacional de Saúde, 2016). The Ministry of Health also identifies anonymization as part of its public SRAG data dissemination procedures.

Reproducibility was supported by documented eligibility rules, version-specific variable definitions, denominator reconciliation, and audit procedures linking aggregate indicators to their analytical records. Although the underlying surveillance datasets are publicly accessible, complete reproduction of the estimates requires the corresponding extracts, harmonization decisions, and rule specifications. Accordingly, the analysis distinguishes publicly available source data from internally maintained technical audit records, whose disclosure remains subject to appropriate data governance considerations (Benchimol et al., 2015).

3 RESULTS

3.1 Surveillance Records and Territorial Coverage

The analysis comprised 4,577,627 severe acute respiratory syndrome (SRAG) surveillance records reported in Brazil between 2016 and 2025. Annual notification volumes varied substantially, particularly during the COVID-19 pandemic. Records increased from 48,941 in 2019 to 1,206,920 in 2020 and reached 1,745,672 in 2021. Together, these two years accounted for approximately 64.5% of the analytical dataset.

Subsequent annual volumes declined to 560,577 in 2022, 279,453 in 2023, and 267,986 in 2024, followed by 336,391 in 2025. This distribution provides the context for interpreting temporal changes in information quality across periods characterized by markedly different notification volumes. Table 3 presents the annual distribution and corresponding national quality indicators.

Table 3. Annual Distribution of SRAG Surveillance Records and National Information Quality Indicators, Brazil, 2016 to 2025

Year	Records	Valid residence state	Unassigned	Informative completeness (%)	Inconsistency (%)	Median delay, days (IQR)
2016	54,380	54,380	0	95.564	0.668	4 (2 to 7)
2017	29,551	29,551	0	96.434	0.618	4 (2 to 7)
2018	47,756	47,756	0	96.215	0.591	4 (2 to 7)
2019	48,941	48,904	37	95.995	1.250	4 (2 to 7)
2020	1,206,920	1,206,807	113	88.506	0.723	6 (3 to 10)
2021	1,745,672	1,745,412	260	87.578	0.775	8 (4 to 11)
2022	560,577	560,449	128	87.321	1.607	4 (2 to 7)

2023	279,453	279,387	66	90.378	2.297	4 (2 to 7)
2024	267,986	267,908	78	91.583	2.322	4 (2 to 7)
2025	336,391	336,282	109	92.981	2.454	4 (2 to 7)
Total	4,577,627	4,576,836	791	88.91	1.1867	Annual estimates

Note. IQR = interquartile range. Informative completeness represents the pooled proportion of fully informative field-level opportunities. Inconsistency refers to violations per eligible rule opportunity, with rule applicability varying across reporting periods. Overall percentages are pooled estimates rather than arithmetic averages of annual values. The 2025 observations correspond to the database extraction dated September 14, 2026.

Source: Authors' calculations based on Brazilian Ministry of Health SRAG surveillance databases.

Geographic information was available for nearly the entire dataset. Residence-state codes were valid in 4,576,836 records, equivalent to 99.9827% of all observations. The remaining 791 records (0.0173%) had no valid residence-state assignment and were retained in national estimates without geographic imputation. Notification-state information was informative in 4,567,032 records (99.7685%), while 10,595 observations lacked a usable notification-state value. No nonempty invalid residence-state codes were identified in the original geographic validation.

Territorial completeness was interpreted at two distinct analytical levels. National availability of residence-state information was assessed against all 4,577,627 records, whereas geographic eligibility for state-level comparisons was restricted to observations with valid residence-state codes. This distinction prevented the conditional completeness of geographically assignable records from being interpreted as evidence that residence-state information was universally available.

The resulting territorial panel contained 270 combinations of federative unit and year, covering the five Brazilian macroregions and all 27 federative units. Unassigned records remained in national estimates but were not redistributed across states or macroregions. Because municipality-level coding was not independently validated, geographic comparisons were limited to state of residence. Accordingly, territorial attribution describes the available surveillance information without establishing the location of infection or the institutional origin of recording deficiencies.

3.2 Temporal Evolution of Completeness and Distribution of Information Gaps

Across the 25 longitudinally evaluated fields, 106,544,628 eligible field-level opportunities were identified, of which 94,727,552 contained fully informative values. Overall informative completeness reached 88.91%, leaving 11,817,076 opportunities without fully usable information under the original analytical classification. Before the COVID-19 pandemic, annual completeness remained relatively stable, ranging from 95.56% to 96.43% between 2016 and 2019. This pattern changed in 2020, when completeness decreased to 88.51%, followed by 87.58% in 2021 and 87.32% in 2022. A subsequent recovery was observed, reaching 90.38% in 2023, 91.58% in 2024, and 92.98% in 2025. Nevertheless, the final estimate remained below the levels recorded before 2020.

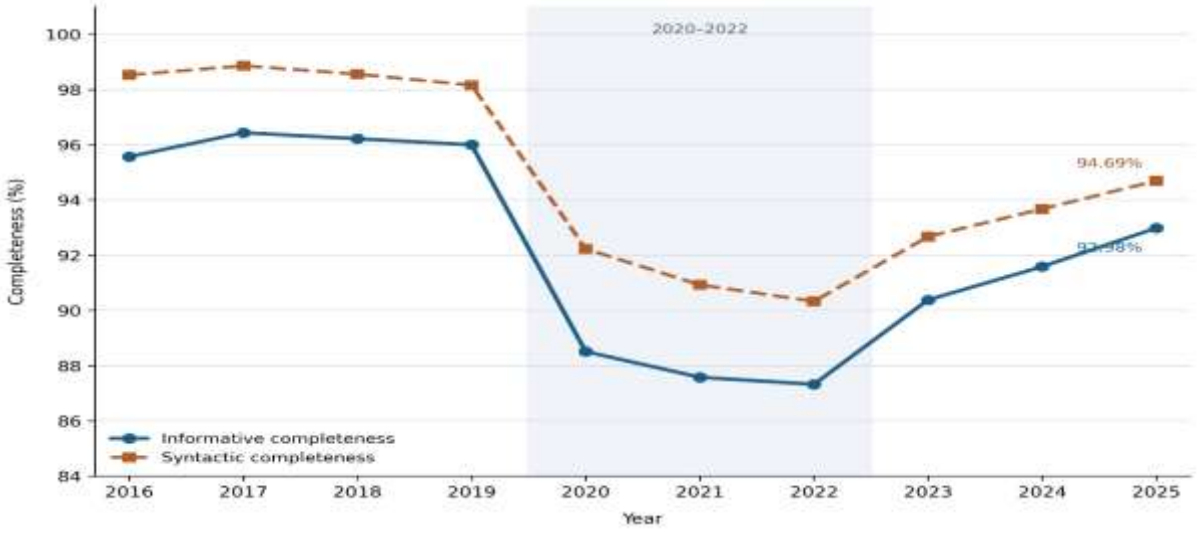


Figure 1. Temporal Evolution of Informative and Syntactic Completeness in SRAG Surveillance Records, Brazil, 2016 to 2025

Note. Informative completeness represents the proportion of eligible field-level observations containing substantively usable information, whereas syntactic completeness includes formally populated values regardless of their analytical usefulness. The shaded area identifies 2020 to 2022. **Source:** Authors' calculations based on Brazilian Ministry of Health SRAG surveillance databases.

As illustrated in Figure 1, syntactic completeness consistently exceeded informative completeness throughout the observation period. In 2016, syntactic completeness reached 98.52%, compared with 95.56% informative completeness, a difference of 2.96 percentage points. The gap widened to 3.72 percentage points in 2020, when the corresponding indicators were 92.23% and 88.51%. By 2025, this difference had decreased to 1.71 percentage points. Although both measures followed broadly similar temporal trajectories, their persistent separation demonstrates that the proportion of populated fields was systematically greater than the proportion containing information classified as fully usable.

Field-level results revealed pronounced heterogeneity. Educational attainment had the lowest informative completeness (34.74%) and accounted for 20.49% of all noninformative opportunities. Chest radiography results followed, with 55.03% completeness and a contribution of 17.42% to the overall information gap. Together, these variables represented approximately 37.91% of noninformative opportunities. Respiratory discomfort, oxygen saturation below 95%, race or skin color, fever, and ventilatory support also contributed substantially to the observed deficit. Table 4 presents the distribution across all 25 fields, preserving the original eligibility criteria and distinguishing field-level opportunities from the total number of surveillance records.

Table 4. Informative Completeness of the 25 Longitudinal Surveillance Fields and Contribution to the Total Information Gap, Brazil, 2016 to 2025

Field	Eligible opportunities	Informative values	Noninformative values	Completeness (%)	Gap contribution (%)
Educational attainment	3,709,917	1,288,843	2,421,074	34.740	20.488
Chest radiography result	4,577,627	2,519,228	2,058,399	55.033	17.419
Respiratory discomfort	4,577,627	3,743,067	834,560	81.769	7.062
Oxygen saturation below 95%	4,577,627	3,776,547	801,080	82.500	6.779
Race or skin color	4,577,627	3,815,657	761,970	83.354	6.448
Fever	4,577,627	3,849,742	727,885	84.099	6.160
Ventilatory support	4,577,627	3,850,030	727,597	84.105	6.157
ICU admission	4,577,627	3,914,096	663,531	85.505	5.615
Dyspnea	4,577,627	3,983,244	594,383	87.015	5.030
Cough	4,577,627	4,030,219	547,408	88.042	4.632
Pregnancy status	1,737,308	1,303,098	434,210	75.007	3.674
Clinical outcome	4,577,627	4,156,936	420,691	90.810	3.560
Specimen collection	4,577,627	4,394,364	183,263	95.997	1.551
Final classification	4,577,627	4,415,779	161,848	96.464	1.370
Case closure date	4,416,362	4,274,509	141,853	96.788	1.200
Hospitalization	4,577,627	4,453,676	123,951	97.292	1.049
Confirmation criterion	4,416,362	4,318,695	97,667	97.789	0.826
Hospital admission date	4,354,895	4,285,385	69,510	98.404	0.588
ICU entry date	1,309,068	1,276,622	32,446	97.521	0.275
Notification state	4,577,627	4,567,032	10,595	99.769	0.090
Specimen collection date	4,204,221	4,201,884	2,337	99.944	0.020
Sex	4,577,627	4,576,809	818	99.982	0.007
Notification date	4,577,627	4,577,627	0	100.000	0.000
Symptom onset date	4,577,627	4,577,627	0	100.000	0.000
Residence state, geographically eligible	4,576,836	4,576,836	0	100.000	0.000

Note. ICU = intensive care unit. Field-specific denominators reflect the eligibility rules used in the original analytical protocol. Pregnancy status was evaluated only among eligible records, and its noninformative total is reported without subdividing categories whose classification requires additional reconciliation. For residence state, 100% refers exclusively to geographically eligible observations; national availability was 99.9827%, as reported in Section 3.1.

Source: Authors' calculations using Brazilian Ministry of Health SRAG surveillance databases.

Differences between fields were not limited to their completeness percentages. Educational attainment contained 1,173,693 observations classified as unknown or ignored and 1,247,368 blank entries. Chest radiography results included 404,479 unknown

or ignored observations and 1,653,920 blank fields. Race or skin color displayed another pattern, with 712,752 unknown or ignored responses and 49,218 blanks. These distributions show that noninformative records were not composed exclusively of empty fields; explicitly recorded categories without substantive analytical content also contributed considerably.

Clinical variables presented similarly heterogeneous results. Respiratory discomfort and oxygen saturation below 95% reached informative completeness levels of 81.77% and 82.50%, respectively, while dyspnea reached 87.02% and cough 88.04%. In contrast, notification date and symptom onset date were complete throughout the analyzed records, and sex exceeded 99.98% completeness. Pregnancy status presented 75.01% informative completeness among the 1,737,308 opportunities defined as eligible under the original protocol, indicating a substantial deficit within this specific analytical denominator. The results therefore demonstrate variable-specific patterns of information availability rather than a uniformly distributed incompleteness problem.

3.3 Documentary Conformance and Patterns of Internal Inconsistency

Internal consistency assessment identified 711,323 violations across 59,939,228 eligible rule-level opportunities, corresponding to an aggregate inconsistency rate of 1.1867%. The distribution of violations was highly concentrated: three of the 20 verification rules accounted for 682,841 occurrences, or approximately 96.00% of the total. Pregnancy applicability according to sex and age contributed 267,616 violations, followed by educational attainment applicability according to age (223,197) and discrepancies between recorded age and age derived from valid dates (192,028). These three verification rules affected 638,281 distinct records, representing 13.94% of the complete dataset. Since individual records could be evaluated by multiple rules, the number of violations should not be interpreted as an equivalent number of patients or unique surveillance records.

Documentary conformance assessment identified 1,361,211 strict violations across 68,808,095 mandatory or key requirement opportunities, resulting in an aggregate nonconformance rate of 1.9783%. Unlike internal consistency, this dimension assessed compliance with version-specific documentary requirements, including mandatory fields, conditional obligations, and admissible coding domains. Specific findings included 2,295 missing collection dates among 116,180 eligible historical specimen collection records and 418,126 observations in 2020 containing a travel-history value outside the documented coding domain. Table 5 summarizes the principal findings while preserving the distinct analytical denominators and the conceptual separation between consistency and documentary conformance.

Table 5. Major Internal Consistency Violations and Documentary Nonconformance Indicators in SRAG Surveillance Records, Brazil, 2016 to 2025

Indicator	Period	Evaluation opportunities	Violations	Rate (%)
Internal consistency				
Pregnancy applicability according to sex and age	2016 to 2025	4,576,936	267,616	5.847
Educational attainment applicability according to age	2016 to 2025	4,548,344	223,197	4.907
Recorded age versus date-derived age	2019 to 2025	4,442,038	192,028	4.323
Remaining 17 consistency rules	2016 to 2025	46,371,910	28,482	0.061
Total internal consistency	2016 to 2025	59,939,228	711,323	1.1867
Documentary conformance				
Strict mandatory or key requirements	2016 to 2025	68,808,095	1,361,211	1.9783
Missing collection date when specimen collection was indicated	2016 to 2018	116,180	2,295	1.975
Travel-history value outside documented domain	2020	1,206,920	418,126	34.644
Missing destination country when travel was indicated	2020	1,001	0	0.000

Note. Each indicator has its own eligibility criteria and denominator. A record may contribute to more than one consistency or documentary conformance verification. The documentary examples are illustrative findings from the original audit and do not constitute additional, mutually exclusive components of the aggregate rate. Violations indicate disagreement with an implemented documentary or logical rule and do not establish which underlying clinical information is correct.

Source: Authors' calculations and documentary validation protocol based on Brazilian Ministry of Health surveillance forms.

Pregnancy applicability produced the largest number of violations, accounting for 37.62% of all internal inconsistencies. Educational attainment applicability represented another 31.38%, whereas recorded age discrepancies contributed 27.00%. Together, these findings show that most detected incompatibilities involved demographic classification and the logical relationship between fields, rather than being distributed evenly across the surveillance instrument. Independent recalculation of the three dominant rules found no discrepancies between the reconstructed results and the original analytical indicators. This finding supports the computational reproducibility of the implemented verifications while remaining distinct from an independent assessment of their documentary and clinical validity.

Among age-related violations, numerical discrepancies predominated over differences in recorded age units. Of the 192,028 occurrences, 155,795 involved disagreement in the age value despite agreement in the corresponding unit, 28,692 involved unit discrepancies, and 7,541 involved values considered inadmissible for the recorded unit. These findings identify distinct types of disagreement within the available age information. However, comparison between recorded age and date-derived age does not independently establish which source contains the correct demographic information.

The aggregate inconsistency rate varied considerably across years. Values remained below 0.8% in 2016 to 2018 and 2020 to 2021, with a temporary increase to 1.25% in 2019. Thereafter, the rate increased from 1.61% in 2022 to 2.30% in 2023, 2.32% in 2024, and 2.45% in 2025. Because the number and composition of eligible verification rules changed across reporting periods, the original study also examined a fixed set of two rules available throughout the complete series. This restricted indicator increased from 2.70% in 2016 to 4.50% in 2019, remained near 4% during 2020 and 2021, and subsequently reached 7.25% in 2022, 9.26% in 2023, 9.14% in 2024, and 9.56% in 2025. Both measures therefore showed higher values in recent years, although their different definitions preclude direct comparison of their absolute magnitudes.

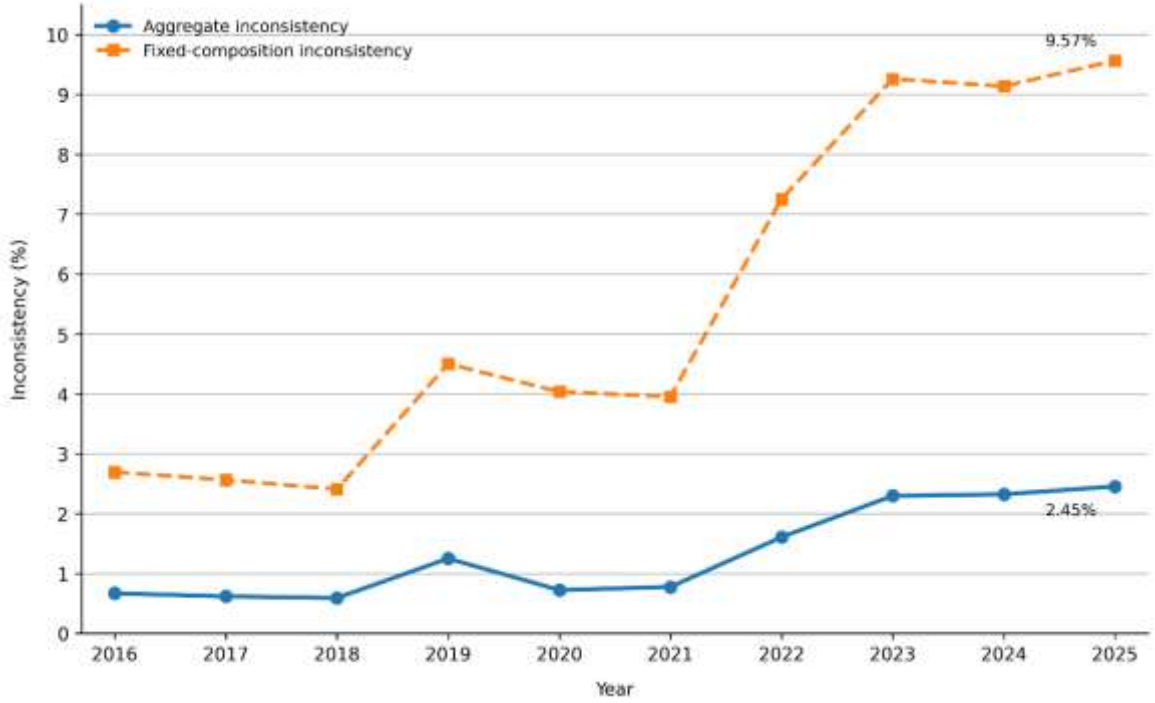


Figure 2. Temporal Evolution of Internal Inconsistency in SRAG Surveillance Records, Brazil, 2016 to 2025

Note. Aggregate inconsistency represents violations per eligible rule opportunity considering all rules applicable in each reporting period. Fixed-composition inconsistency is restricted to the two rules evaluated throughout 2016 to 2025, namely pregnancy applicability according to sex and age and educational attainment applicability according to age. The two indicators have different scopes and denominators and should not be interpreted as directly interchangeable.

Source: Authors' calculations based on Brazilian Ministry of Health SRAG surveillance databases.

Figure 2 illustrates the difference between the comprehensive inconsistency indicator and the narrower fixed-composition measure. The latter exhibited greater relative variation, particularly after 2021, because it concentrated on two verification rules responsible for a substantial proportion of the detected violations. Nevertheless, the upward trajectory observed in the recent period was not restricted to the changing composition of the complete rule set. The persistence of this pattern under a constant selection of rules provides additional descriptive evidence of temporal changes in recorded compatibility, while differences in record characteristics and eligibility may still influence the annual estimates.

Documentary conformance results revealed a separate set of information quality problems. In 2020, 34.64% of travel-history

records contained the value zero, which was outside the domain documented for that version of the form. No inferential recoding was performed. Conversely, the destination-country field was populated in all 1,001 records for which travel history was positively indicated. This contrast demonstrates that compliance with coding domains and compliance with conditional field requirements may differ substantially, even within related surveillance information.

3.4 Notification Timeliness and Territorial Heterogeneity

Regional comparisons identified substantial differences in informative completeness throughout the observation period. Before 2020, most macroregions exhibited completeness levels above 95%, although lower values were observed in the Northeast during several years. During the pandemic, completeness declined across all five macroregions, with the Northeast recording 84.01% in 2020, 82.93% in 2021, and 81.53% in 2022. The South maintained comparatively higher values of 92.73%, 90.92%, and 90.95% during the same years. By 2025, informative completeness ranged from 90.17% in the Northeast to 95.11% in the Central-West, revealing persistent geographic heterogeneity despite the recovery observed after 2022.

Internal inconsistency followed a different regional pattern. Rates increased in all five macroregions after 2021, although the extent and timing of change varied. In 2025, inconsistency reached 2.58% in the Northeast and 2.57% in the Southeast, compared with 2.14% in the North and 2.23% in the South. Consequently, macroregions with relatively high informative completeness did not necessarily present the lowest inconsistency rates. Figure 3 displays the regional trajectories of the two indicators using separate scales appropriate to their respective magnitudes.

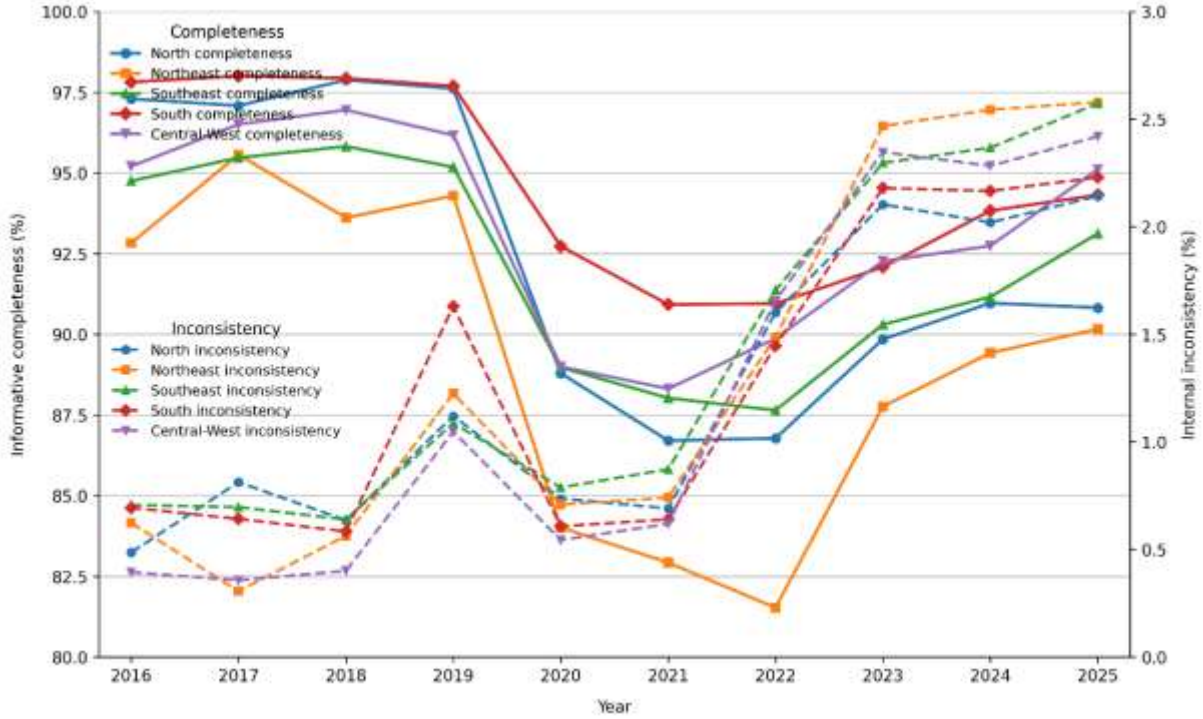


Figure 3. Informative Completeness and Internal Inconsistency of SRAG Surveillance Records by Brazilian Macroregion, 2016 to 2025

Note. Solid lines represent informative completeness, and dashed lines represent internal inconsistency. Informative completeness corresponds to the proportion of eligible field-level observations containing substantively usable information. Internal inconsistency corresponds to violations per eligible rule opportunity. Territorial classification was based on state of residence aggregated to the five Brazilian macroregions. Because the two indicators have different magnitudes, the figure uses separate vertical axes.

Source: Authors' calculations based on Brazilian Ministry of Health SRAG surveillance databases.

Regional differences were particularly pronounced during the years of greatest pandemic-related notification activity. Figure 3 shows that the Northeast experienced a comparatively greater decline in completeness, while the South maintained higher percentages through much of the period. In contrast, inconsistency rates followed a less stable geographic ranking, with different macroregions occupying the highest positions across years. These patterns demonstrate that territorial variation depended on the particular quality dimension under examination, preventing a single indicator from adequately characterizing regional surveillance information quality.

Notification timeliness also changed during the study period. The national median interval between symptom onset and notification was four days, with an interquartile range of two to seven days, from 2016 to 2019. In 2020, the median increased to

six days (IQR: 3 to 10), reaching eight days in 2021 (IQR: 4 to 11). From 2022 through 2025, the median returned to four days (IQR: 2 to 7). Only one negative notification interval was identified throughout the dataset, and its exclusion did not alter any annual median.

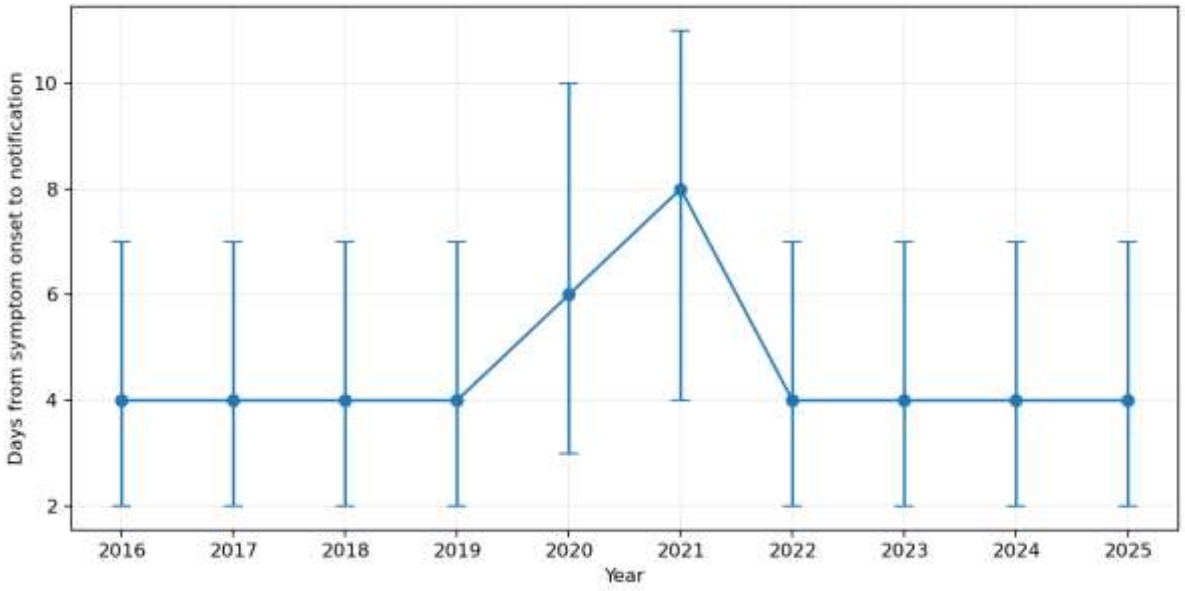


Figure 4. Temporal Evolution of Notification Delay in SRAG Surveillance Records, Brazil, 2016 to 2025
Note. Points indicate annual median notification delay, and vertical intervals represent the first and third quartiles. Delay was measured in calendar days between symptom onset and notification.
Source: Authors' calculations based on the original annual surveillance series.

Figure 4 highlights a concentrated deterioration in notification timeliness during 2020 and 2021. The upper quartile increased from seven days before the pandemic to ten days in 2020 and eleven days in 2021, indicating that the change extended beyond the median alone. Regional medians also increased during these years, reaching values between six and eight days, before returning to four days across all five macroregions from 2022 onward. This recovery in notification timeliness occurred alongside continued territorial differences in completeness and increasing inconsistency rates, reinforcing the descriptive distinction between the evaluated quality dimensions.

Table 6. Information Quality Indicators by Brazilian Macroregion and Year, 2016 to 2025

Year	Macroregion	Records	Completeness (%)	Inconsistency (%)	Median delay (days)
2016	North	1,827	97.298	0.486	5
2016	Northeast	4,367	92.830	0.624	5
2016	Southeast	29,316	94.752	0.707	4
2016	South	15,026	97.817	0.694	4
2016	Central-West	3,844	95.204	0.394	4
2017	North	1,689	97.085	0.813	5
2017	Northeast	3,532	95.563	0.306	5
2017	Southeast	13,022	95.473	0.697	4
2017	South	9,115	98.008	0.642	4
2017	Central-West	2,193	96.509	0.357	4
2018	North	1,996	97.881	0.636	5
2018	Northeast	7,981	93.612	0.564	5
2018	Southeast	20,684	95.824	0.639	4
2018	South	12,791	97.935	0.584	4
2018	Central-West	4,304	96.951	0.401	4
2019	North	3,893	97.615	1.120	4
2019	Northeast	7,467	94.294	1.225	5
2019	Southeast	19,638	95.181	1.087	5

2019	South	12,658	97.691	1.630	4
2019	Central-West	5,248	96.172	1.048	4
2020	North	87,244	88.795	0.737	8
2020	Northeast	238,519	84.012	0.709	7
2020	Southeast	609,426	88.977	0.788	6
2020	South	164,482	92.733	0.608	6
2020	Central-West	107,136	89.001	0.544	7
2021	North	106,259	86.708	0.691	8
2021	Northeast	314,912	82.931	0.741	8
2021	Southeast	860,262	88.027	0.873	7
2021	South	306,902	90.924	0.640	8
2021	Central-West	157,077	88.314	0.619	8
2022	North	24,715	86.779	1.601	4
2022	Northeast	105,326	81.529	1.488	4
2022	Southeast	274,248	87.646	1.706	4
2022	South	109,833	90.952	1.447	4
2022	Central-West	46,327	89.875	1.657	4
2023	North	17,244	89.849	2.104	4
2023	Northeast	50,860	87.765	2.468	4
2023	Southeast	127,680	90.306	2.297	4
2023	South	55,597	92.086	2.180	4
2023	Central-West	28,006	92.269	2.347	4
2024	North	17,934	90.968	2.020	4
2024	Northeast	47,044	89.425	2.544	4
2024	Southeast	119,060	91.160	2.367	4
2024	South	57,520	93.832	2.166	4
2024	Central-West	26,350	92.742	2.283	4
2025	North	23,430	90.826	2.143	4
2025	Northeast	53,008	90.165	2.579	4
2025	Southeast	152,086	93.124	2.573	4
2025	South	70,519	94.319	2.230	4
2025	Central-West	37,239	95.114	2.420	4

Note. Completeness represents the proportion of fully informative eligible field-level opportunities. Inconsistency represents violations per eligible rule opportunity. Regional assignment was based on residence state. Records without valid geographic assignment were excluded only from regional analyses. Regional medians cannot be averaged to obtain national medians.
Source: Authors' calculations based on Brazilian Ministry of Health SRAG surveillance records.

3.5 Notification Volume, Information Quality, and Robustness of Associations

The fixed-effects regression models did not identify statistically significant associations between annual notification volume and the three information quality outcomes. Under the weighted least squares (WLS) specification, doubling the annual number of notifications was associated with an estimated reduction of 0.909 percentage points in informative completeness (95% CI [−2.090, 0.271], p = .125), an increase of 0.052 percentage points in inconsistency (95% CI [−0.069, 0.173], p = .385), and a reduction of 0.094 days in median notification delay (95% CI [−0.623, 0.435], p = .718). All confidence intervals included zero. Table 7 presents the main estimates alongside alternative specifications designed to assess their sensitivity to weighting and the inclusion of the most recent reporting year.

Table 7. Associations Between Annual Notification Volume and Information Quality Indicators: Main Models and Sensitivity Analyses, Brazil, 2016 to 2025

Outcome and specification	State-year observations	β (SE)	95% CI	p
Informative completeness				
WLS, main model	270	−0.909 (0.574)	[−2.090, 0.271]	.125
OLS, unweighted	270	0.101	[−0.926, 1.129]	.841

WLS, excluding 2025	243	−0.476	[−1.583, 0.631]	.385
Internal inconsistency				
WLS, main model	270	0.052 (0.059)	[−0.069, 0.173]	.385
OLS, unweighted	270	0.045	[−0.058, 0.148]	.380
WLS, excluding 2025	243	0.067	[−0.046, 0.179]	.233
Median notification delay				
WLS, main model	270	−0.094 (0.258)	[−0.623, 0.435]	.718
OLS, unweighted	270	−0.069	[−0.353, 0.216]	.624
WLS, excluding 2025	243	−0.027	[−0.580, 0.525]	.920

Note. WLS = weighted least squares; OLS = ordinary least squares; SE = cluster-robust standard error; CI = confidence interval. All models included state and year fixed effects. Annual notification volume was transformed using a base-2 logarithm, and coefficients represent changes associated with a doubling of notifications. Completeness and inconsistency coefficients are expressed in percentage points, while notification delay coefficients are expressed in days. WLS weights correspond to the analytical denominator of each outcome. Standard errors in the main models were clustered across 27 federative units.
Source: Authors' statistical analyses.

Alternative model specifications generally preserved the absence of statistically detectable associations. Excluding 2025 reduced the magnitude of the completeness coefficient from −0.909 to −0.476 percentage points, while the inconsistency coefficient increased from 0.052 to 0.067 percentage points. For median notification delay, the coefficient shifted from −0.094 to −0.027 days. None of the corresponding confidence intervals excluded zero, indicating that the statistical evidence remained inconclusive under these specifications.

Differences between weighted and unweighted models were more apparent for informative completeness. The principal WLS estimate was negative, whereas the unweighted ordinary least squares (OLS) coefficient was positive (0.101 percentage points). Although neither association was statistically significant, the change in direction indicates that the estimated relationship depended partly on the relative influence assigned to state-year observations. Conversely, inconsistency coefficients remained positive under both approaches, while notification delay coefficients remained negative. These results distinguish robustness of statistical significance from stability of coefficient direction and magnitude.

Further sensitivity analyses involved successive exclusion of each federative unit. Across the 27 leave-one-state-out specifications, completeness coefficients ranged from −1.111 to −0.550 percentage points, retaining a negative direction. Inconsistency coefficients ranged from 0.030 to 0.078 percentage points and remained positive. Notification delay coefficients varied from −0.220 to 0.033 days, indicating greater sensitivity in their direction. None of these exclusions produced an association meeting the conventional 5% significance criterion in the original analysis.

Overall, the results did not demonstrate statistically detectable associations between annual notification volume and informative completeness, internal inconsistency, or median notification delay after accounting for state and year fixed effects. However, the confidence intervals encompassed associations of different magnitudes, and the estimated coefficients were sensitive to some analytical choices. These findings therefore characterize the statistical evidence obtained under the specified models without establishing the absence of a relationship between surveillance workload and information quality. As emphasized by Cameron and Miller (2015), inference based on a limited number of geographic clusters requires particular caution, especially when interpreting confidence intervals and statistical significance.

The combined findings indicate that the dimensions of information quality followed different trajectories over the observation period. Informative completeness declined sharply during 2020 to 2022 before recovering, while documentary inconsistencies increased in more recent years and notification timeliness returned to earlier levels after 2021. Territorial differences also persisted despite changes in national indicators. These descriptive results, together with the absence of statistically conclusive associations in the adjusted models, provide the empirical basis for examining the implications of information quality for surveillance governance without attributing the observed patterns to institutional mechanisms that were not directly measured.

4 DISCUSSION

4.1 Information Quality and the Reliability of Surveillance Evidence

The findings challenge the assumption that the existence of extensive surveillance databases necessarily guarantees reliable epidemiological evidence. Although informative completeness reached 88.91% across the evaluated field-level opportunities, its substantial decline between 2020 and 2022 revealed vulnerabilities that would have been less apparent if the assessment had relied exclusively on formally populated fields. The persistent difference between informative and syntactic completeness, illustrated in Figure 1, demonstrates that recording information and producing analytically useful information are not equivalent processes.

Kahn et al. (2016) distinguish completeness, conformance, and plausibility as separate properties of electronic health data, reinforcing the importance of evaluating whether recorded values satisfy the conditions required for their intended analytical use.

Particularly concerning was the concentration of information gaps in educational attainment, chest radiography results, and selected clinical and sociodemographic variables. As shown in Table 4, educational attainment alone accounted for 20.49% of noninformative field-level opportunities, while chest radiography results contributed another 17.42%. These findings raise different questions about data reliability. Missing educational information may restrict analyses involving socioeconomic stratification, whereas incomplete radiographic information may reflect limitations in documenting diagnostic procedures, examination results, or applicable reporting categories. Their epidemiological significance therefore depends on the purpose for which each variable is used. Similar concerns were identified by Ribas et al. (2022), who documented weaknesses in the completeness of Brazilian SRAG records during the COVID-19 pandemic.

Internal consistency and documentary conformance revealed an additional dimension of the problem. Table 5 shows that 711,323 inconsistencies occurred across 59,939,228 eligible rule opportunities, while strict documentary nonconformance involved 1,361,211 violations across 68,808,095 opportunities. These indicators cannot be added or interpreted as equivalent estimates because they evaluate different requirements and may overlap at the record level. Nevertheless, their coexistence demonstrates why the proportion of completed fields is insufficient to characterize surveillance data quality. An apparently complete record may contain a value incompatible with the documented coding domain or with another field. Conversely, a record may satisfy its documentary requirements without establishing that the information accurately reflects the underlying clinical event (Kahn et al., 2016).

International evidence places these findings within a broader problem of surveillance reliability. Simpson et al. (2021) identified heterogeneity in the completeness of influenza surveillance information across the Americas. Similarly, Marques et al. (2025) reported differences in completeness and other surveillance attributes among European countries, despite generally favorable completeness in the evaluated severe acute respiratory infection surveillance data. Their findings also identified challenges involving timeliness, representativeness, data linkage, and the availability of sufficiently detailed information. Consequently, the Brazilian results should not be interpreted as an isolated technological deficiency, but as part of a wider challenge involving the production, standardization, and use of epidemiological information.

An important distinction nevertheless emerges between detecting a documentary inconsistency and establishing an incorrect clinical observation. The three dominant verification rules in this study concerned pregnancy applicability, educational attainment applicability, and agreement between recorded and date-derived age. Their concentration, illustrated in Figure 2, indicates that much of the detected inconsistency was associated with demographic representation and conditional field requirements. Yet computational agreement with a verification rule does not establish which recorded value is substantively correct. This distinction is consistent with the conceptual separation between internal verification and external validation proposed by Kahn et al. (2016).

From an institutional perspective, the central question is not simply how many records contain deficiencies, but whether the surveillance system can identify, interpret, and address them before they compromise the production of public health evidence. German et al. (2001) emphasize the importance of data quality and timeliness in surveillance evaluation, while the World Health Organization (2023) recommends structured, recurring assessments using explicit quality metrics. Under this perspective, routine publication of surveillance information should be accompanied by procedures that make its limitations visible. Otherwise, apparent improvements in database coverage may coexist with unresolved weaknesses in informational reliability.

4.2 Territorial Inequalities and Implications for Public Governance

Territorial differences observed in this study reveal that surveillance information quality was not distributed uniformly across Brazil. During 2020 to 2022, the Northeast consistently exhibited lower informative completeness than the other macroregions, reaching 81.53% in 2022. The South maintained comparatively higher values during the same period. Although regional completeness improved subsequently, disparities remained visible in 2025, when estimates ranged from 90.17% in the Northeast to 95.11% in the Central-West. Figure 3 and Table 6 demonstrate that territorial heterogeneity persisted across distinct epidemiological periods, indicating the importance of examining national indicators alongside their geographic distributions.

Such differences acquire particular relevance when information systems are understood as instruments of public governance. Records influence which health problems become statistically visible, how population needs are characterized, and what evidence is available to inform policies and resource allocation. The Organisation for Economic Co-operation and Development (OECD, 2022) identifies data quality, accessibility, interoperability, and institutional responsibility as fundamental elements of health data governance. From this perspective, territorial variation in completeness constitutes more than a technical concern because differences in information availability may affect the capacity to describe health needs consistently across administrative jurisdictions.

Nevertheless, the findings do not establish that territories with lower completeness necessarily possess weaker institutional

capacity. The study did not directly measure financing, staffing, professional qualifications, technological infrastructure, administrative coordination, or the organizational conditions under which records were completed. Consequently, territorial differences may reflect combinations of reporting requirements, case composition, operational processes, and data updating practices. Research by Leandro et al. (2025) and Espírito Santo and Boing (2026) also identified heterogeneity in Brazilian respiratory surveillance records, supporting the relevance of geographic comparisons without resolving the institutional mechanisms responsible for the observed patterns.

Particularly significant is the incomplete recording of educational attainment and race or skin color. These variables are essential for examining social differentiation within epidemiological information, yet their usefulness depends on the availability and consistency of the recorded categories. Educational attainment presented only 34.74% informative completeness, while race or skin color reached 83.35%. Although these percentages arise from different eligibility conditions and should not be interpreted as equivalent failures, they indicate that information necessary for examining social inequalities was less consistently available than several basic identification and notification variables. The problem becomes especially consequential when the same datasets are used to investigate disparities between population groups or identify priorities for public intervention.

The governance implications extend beyond improving field completion rates. If information gaps differ systematically across geographic areas or social variables, analyses based exclusively on available records may offer an incomplete representation of the populations under surveillance. However, the present study did not estimate the direction or magnitude of resulting selection biases. The findings establish limitations in information availability, not the precise consequences of those limitations for specific epidemiological estimates. Recognizing this boundary is essential to avoid replacing one form of uncertainty with another.

WHO data governance principles emphasize responsible stewardship, transparent methods, comparability, and accountability in the collection and use of health information (World Health Organization, n.d.). These principles provide a relevant institutional framework for interpreting the territorial findings, particularly where differences in information quality may affect the visibility of population needs. Accordingly, the evidence supports geographically differentiated quality monitoring, with attention to fields that are especially relevant for social and territorial analyses. Such monitoring would not, by itself, eliminate structural inequalities, but it could improve the recognition of informational disparities that otherwise remain obscured within national averages.

A further finding complicates any attempt to classify territories through a single measure of surveillance performance. Macroregions with comparatively high informative completeness did not consistently exhibit the lowest inconsistency rates. The divergence between these indicators suggests that the ability to populate records and the ability to maintain logical or documentary coherence represent distinct operational challenges. This reinforces the need for multidimensional territorial assessments rather than rankings derived from one aggregate indicator.

4.3 Surveillance System Transformations and Challenges of Longitudinal Comparability

Interpretation of the temporal patterns requires consideration of the institutional and documentary changes affecting Brazilian respiratory surveillance. The transition from Sinan Web Influenza to SIVEP-Gripe in 2019 introduced differences in variable structures, coding domains, reporting requirements, and field applicability. Subsequent revisions further modified the conditions under which particular records could be evaluated. Therefore, a longitudinal indicator may change because of differences in the quality of recorded information, alterations in the instruments used to generate that information, or shifts in the composition of the monitored population. Treating these processes as interchangeable risks attributing methodological variation to deterioration or improvement in surveillance performance (Ministério da Saúde, n.d.; Kahn et al., 2016).

The sharp decline in informative completeness beginning in 2020 coincided with an extraordinary increase in notification volume. Records for 2020 and 2021 represented approximately 64.5% of the entire analytical dataset, reflecting a surveillance period profoundly affected by the COVID-19 pandemic. Although the temporal coincidence is striking, it does not demonstrate that increased workload caused the observed reduction in completeness. Changing clinical profiles, reporting practices, classification requirements, and patterns of record updating may also have contributed. Leandro et al. (2025) documented deterioration in completeness during the pandemic, while Espírito Santo and Boing (2026) reported heterogeneity in the completeness and timeliness of COVID-19-related SRAG records. These findings support the relevance of the pandemic period but do not isolate its organizational effects.

Another important result was the divergence between completeness and inconsistency after 2022. Informative completeness progressively recovered, whereas the aggregate inconsistency rate increased from 1.61% in 2022 to 2.45% in 2025. This contrast challenges the assumption that greater completeness necessarily indicates comprehensive improvement in information quality. However, direct comparisons of the aggregate inconsistency rates require particular caution because the number of evaluable rules and their eligibility conditions changed across periods. The fixed-composition analysis, shown in Figure 2, addressed part of this difficulty by restricting comparisons to two rules available throughout the complete series.

Interestingly, the fixed-composition inconsistency indicator also increased substantially after 2021, reaching 9.56% in 2025. This result indicates that the observed increase cannot be explained exclusively by the incorporation of additional verification

rules into the aggregate measure. Nevertheless, maintaining the same rules does not guarantee that their eligible populations, documentary interpretation, or distribution of underlying characteristics remained unchanged. Thus, the sensitivity analysis strengthens the description of temporal patterns without converting the historical series into a perfectly invariant measure.

The methodological implications are substantial. Table 1 documents why field availability and eligibility required version-specific treatment, while Table 2 demonstrates how the denominators of different quality indicators depended on the records and conditions that could legitimately be evaluated. Kahn et al. (2016) emphasize that conformance and plausibility assessments depend on explicit definitions and expected relationships between values. Similarly, the World Health Organization (2023) highlights the importance of transparent metrics and denominators in routine information quality assessments. Applying these principles to historical surveillance databases requires distinguishing changes in the measurement framework from changes in the underlying information.

International findings reinforce this concern. Marques et al. (2025) identified heterogeneity in surveillance organization and reporting practices across European countries, including limitations associated with system differences, geographic coverage, and manual data extraction. Although the contexts are not directly equivalent, these observations demonstrate that standardization and comparability cannot be assumed merely because records are assembled within a shared surveillance framework. Historical analyses therefore require explicit documentation of how reporting instruments evolve and how these transformations affect the interpretation of indicators.

Such considerations are especially relevant for 2025, whose records represent the extraction available in September 2026 rather than a permanently closed dataset. Retrospective updates may modify both record counts and information quality indicators. Consequently, the observed recovery in completeness and increase in inconsistency should be interpreted as properties of the analyzed database versions, not immutable characteristics of the surveillance system. This distinction preserves the empirical contribution of the longitudinal analysis while recognizing the dynamic nature of routinely updated administrative data.

4.4 Methodological Contributions and Implications for Continuous Quality Monitoring

The principal methodological contribution of this study lies in integrating complementary information quality dimensions while preserving their distinct analytical meanings. Informative completeness evaluated the availability of substantively usable values; documentary conformance assessed compliance with version-specific requirements; internal consistency examined logical relationships between fields; and notification timeliness characterized the temporal interval between symptom onset and reporting. Rather than combining these properties into a composite score, the analytical framework maintained separate indicators, eligibility conditions, and denominators. This approach is consistent with the multidimensional data quality framework proposed by Kahn et al. (2016) and with the surveillance evaluation principles established by German et al. (2001).

A particularly relevant contribution concerns the distinction between syntactic completeness and informative completeness. Figure 1 demonstrates that formal field population consistently exceeded the proportion of analytically usable values. This distinction has practical implications for automated dashboards and institutional monitoring, where simple counts of nonempty fields may overestimate the availability of information suitable for epidemiological analysis. Consequently, quality assessment procedures should make explicit whether an indicator measures field population, usable content, documentary compliance, or logical coherence. The World Health Organization (2023) recommends systematic quality reviews and clearly defined metrics, supporting the value of differentiated indicators for routine monitoring.

Version-specific denominators constitute another important feature. By distinguishing structural absence, conditional nonapplicability, and actual deficiencies in required information, the study sought to reduce the risk of classifying records as incomplete merely because a variable did not exist or was not applicable under a particular notification form. This principle is especially important for historical databases assembled from successive information systems. Nevertheless, denominator definitions must remain independently auditable, since inappropriate exclusions can create misleadingly favorable completeness estimates. The distinction between national residence-state availability and completeness among geographically assignable records illustrates why denominator construction is itself an essential component of information quality evaluation.

Independent auditing provided additional support for the integrity of the analytical procedures. The three dominant consistency rules were recalculated directly from the underlying fields and reconciled with their original indicators. Such agreement strengthens confidence that the implemented calculations reproduce the specified logical conditions. It does not, however, establish that every documentary assumption is correct or that discrepancies correspond to clinically inaccurate information. This distinction between computational verification and substantive validation is fundamental to responsible interpretation of automated quality assessments (Kahn et al., 2016; Benchimol et al., 2015).

Statistical analyses offered a complementary perspective by examining whether annual notification volume was associated with the evaluated quality dimensions. After accounting for state and year fixed effects, the principal models did not identify statistically detectable associations between volume and completeness, inconsistency, or median notification delay. The findings suggest that notification volume alone was insufficient to explain the observed variation within the specified analytical

framework. However, the estimates remained sensitive to certain modeling choices, particularly the weighting of completeness observations. As Cameron and Miller (2015) demonstrate, inference using cluster-robust standard errors requires attention to the number of independent clusters and the assumptions underlying variance estimation.

For public administration, these findings suggest a monitoring strategy based on several complementary measures rather than a single performance target. Periodic assessments could distinguish information availability from documentary validity, identify recurrent incompatibilities, and track the timeliness of surveillance reporting across territories and reporting periods. Such an approach would also permit more targeted examination of variables that disproportionately contribute to information gaps. The OECD (2022) emphasizes that effective health data governance depends on institutional arrangements supporting data quality, accessibility, interoperability, and responsible use, providing a broader framework for these applications.

Ultimately, continuous quality monitoring should not be reduced to detecting deviations from technical rules. Its institutional value depends on whether identified deficiencies can inform revisions to recording procedures, documentation, professional support, and information management practices. Although the present study did not evaluate the effectiveness of such interventions, its analytical framework identifies measurable conditions that may guide their prioritization and subsequent assessment. This offers a practical contribution to surveillance governance without presenting potential improvements as outcomes already demonstrated by the research.

4.5 Study Limitations and Scope of Inference

Several limitations must be considered when interpreting the findings. First, the analysis relied exclusively on secondary surveillance records collected for routine public health purposes. These databases reflect not only epidemiological events but also reporting procedures, eligibility conditions, administrative updates, and decisions regarding information entry. Consequently, observed deficiencies cannot be attributed to individual professionals, health facilities, or specific institutional mechanisms. The STROBE and RECORD reporting frameworks emphasize the importance of documenting such limitations when interpreting observational analyses based on routinely collected health information (von Elm et al., 2007; Benchimol et al., 2015).

Documentary verification also has an inherent epistemological limitation. Logical incompatibility between fields does not determine which recorded value is correct, nor does compliance with a coding requirement establish correspondence with the actual clinical condition. The pregnancy, educational attainment, and age verification rules illustrate this distinction. Although independent recalculation supported their computational consistency, the analysis did not include clinical chart review, external reference standards, or direct validation of the underlying observations. Therefore, the findings should be interpreted as evidence of documentary and logical properties rather than definitive estimates of clinical recording errors (Kahn et al., 2016).

Longitudinal comparability represents another important constraint. The transition between surveillance systems, subsequent revisions of notification forms, and changes in documentary applicability affected the opportunities available for quality evaluation. Although harmonization procedures and fixed-composition sensitivity analyses reduced some sources of incompatibility, they could not guarantee complete equivalence across reporting periods. Moreover, the 25-field panel did not encompass every variable introduced into more recent versions of SIVEP-Gripe. The resulting indicators therefore characterize a selected longitudinal information framework rather than the totality of information generated by the surveillance system.

Geographic analyses were restricted to federative units and macroregions of residence. Municipality-level information was not independently validated, and the state of notification was not treated as equivalent to the location of infection. Furthermore, differences between territories may reflect changes in the composition of surveillance records rather than differences in institutional capacity alone. Without direct measures of staffing, financing, technological infrastructure, or administrative organization, the analysis cannot establish the mechanisms responsible for geographic disparities. These restrictions are particularly relevant when connecting territorial patterns to broader debates about public governance.

The aggregate nature of several indicators also requires caution. Completeness percentages were calculated using eligible field-level opportunities, whereas inconsistency and documentary conformance rates were based on distinct sets of rule-level or requirement-level opportunities. Their denominators therefore differed in size and conceptual meaning. In addition, the concentration of consistency violations in three rules meant that the aggregate rate could obscure substantial variation between individual verification conditions. Interpretations based exclusively on pooled indicators might consequently underestimate the importance of specific documentary problems or misrepresent their prevalence among individual records.

Statistical inference was constrained by the observational design, the use of annual state-level aggregates, and the limited number of geographic clusters. Although fixed effects controlled for time-invariant state characteristics and common annual variation, unobserved time-varying determinants remained possible. Weighted and unweighted specifications also produced different coefficient estimates, particularly for informative completeness. The absence of statistically significant associations should therefore not be interpreted as evidence that notification volume has no relationship with information quality. Cameron and Miller (2015) highlight the importance of cautious inference when cluster-based variance estimation relies on a relatively small number of independent groups.

Finally, surveillance databases remain subject to retrospective modification. The 2025 records represented the version available at the documented extraction date, and subsequent updates may alter both notification counts and the information contained in individual records. While the exclusion of 2025 was examined as a sensitivity analysis, the findings remain conditional on the database versions analyzed. These limitations do not invalidate the observed patterns, but they define the boundaries within which conclusions about information quality, territorial disparities, and surveillance governance can be sustained.

Taken together, the methodological constraints reinforce the importance of distinguishing observed data properties from explanations of their institutional origins. The study provides evidence of variation in informative completeness, documentary conformance, internal consistency, and notification timeliness across time and territory. It does not establish the causal mechanisms producing these variations or directly measure the effectiveness of governance arrangements. Its contribution therefore rests on identifying and characterizing the informational conditions under which epidemiological evidence is produced, offering a foundation for more transparent and analytically defensible surveillance quality assessment.

5 CONCLUSION

This study demonstrated substantial temporal and territorial variation in the quality of Brazilian severe acute respiratory syndrome surveillance records between 2016 and 2025. Informative completeness declined markedly during the COVID-19 pandemic and subsequently recovered, while internal inconsistencies increased in recent years and notification timeliness returned to earlier levels. Persistent regional disparities and substantial information gaps in sociodemographic and clinical variables revealed limitations that may compromise the reliability and analytical usefulness of epidemiological evidence.

Importantly, these findings challenge the assumption that formally completed records necessarily constitute reliable information. The multidimensional assessment demonstrated that completeness, documentary conformance, internal consistency, and timeliness represent distinct but complementary properties. Their longitudinal evaluation, supported by version-specific eligibility criteria, provides a more comprehensive understanding of surveillance information quality. Nevertheless, the reliance on secondary records and the absence of direct institutional assessment limit conclusions regarding the underlying causes of the observed disparities.

Strengthening epidemiological surveillance governance requires systematic quality monitoring that extends beyond recording coverage to encompass informational usability, documentary coherence, and territorial disparities. Future research should examine how organizational conditions, technological infrastructure, and data management practices influence these dimensions, including the effectiveness of institutional interventions aimed at improving record quality. By identifying critical weaknesses and establishing a multidimensional analytical framework, this study contributes to more transparent surveillance assessment and provides evidence to support more reliable and equitable public health decision-making.

DECLARATIONS

Ethics Approval and Consent to Participate

This study used exclusively publicly available, anonymized secondary data from the Brazilian Ministry of Health's epidemiological surveillance systems. No direct interaction with human participants or access to personally identifiable information occurred. In accordance with Brazilian National Health Council Resolution No. 510/2016, Article 1, sole paragraph, research involving publicly accessible information is not subject to registration or review by the Research Ethics Committee and National Research Ethics Commission system (CEP/CONEP). Individual informed consent was therefore not applicable.

Data Availability

The datasets analyzed in this study are publicly accessible through the Brazilian Ministry of Health's Open Data Portal (OpenDataSUS), including historical Sinan Web Influenza and SIVEP-Gripe records. The data sources, extraction dates, eligibility criteria, and analytical procedures are described in the Methods section.

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Conflicts of Interest

The author declares no financial, professional, or institutional conflicts of interest related to this research.

Author Contributions

The sole author was responsible for the study's conceptualization, methodology, data acquisition and curation, formal analysis, investigation, interpretation of findings, manuscript preparation, critical revision, and approval of the final version.

Reproducibility and Research Transparency

The study employed documented data harmonization procedures, version-specific eligibility criteria, explicit analytical denominators, internal consistency verification rules, and sensitivity analyses. Data integrity assessments and independent recalculations were conducted to strengthen analytical reliability. Reproducibility is supported by the public availability of the original datasets and the methodological specifications presented in the article, subject to the use of the corresponding database versions and extraction dates.

Academic Origin of the Study

This article is derived from the author's master's dissertation, defended in 2026 within the Graduate Program in Dynamics of Semiarid Development (Programa de Pós-Graduação em Dinâmicas de Desenvolvimento do Semiárido, PPGDiDeS) at the Federal University of Vale do São Francisco (Universidade Federal do Vale do São Francisco, UNIVASF), Brazil. The research findings were reorganized and expanded into an original scientific article for international publication.

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