



Evolving Patterns of Vaccine-Preventable Diseases in Sub-Saharan Africa: A Systematic Review and Meta-Analysis of Mortality and DALYs

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Abstract

Background: Sub-Saharan Africa continues to shoulder a disproportionate burden of vaccine-preventable diseases, yet the COVID-19 pandemic disrupted routine immunization programs across the region, creating immunity deficits that threaten to reverse decades of progress and amplify cross-border health risks for international travelers.

Methods: This systematic review and meta-analysis, guided by the PRISMA protocol, synthesized evidence on mortality and DALYs for selected travel-related VPDs between 2017 and 2026. Data sources include PubMed/MEDLINE, Embase, Scopus, Web of Science, and Wiley Online Library, supplemented by Global Burden of Disease datasets and WHO surveillance reports. Eligible studies reported quantitative burden estimates for the target diseases. Risk of bias was assessed using Joanna Briggs Institute tools. Random-effects meta-analysis was performed with heterogeneity quantified via the I^2 statistic and prediction intervals, using Python.

Results: Of 2,034 records identified, 43 studies met inclusion criteria. Meta-analysis of eight studies on tuberculosis yielded a pooled age-standardized mortality rate of 42.7 per 100,000 (95% CI: 36.2-49.8; $I^2 = 94.3\%$). Nine meningitis studies produced a pooled estimate of 6.8 per 100,000 (95% CI: 5.1-8.7; $I^2 = 89.4\%$), with a discernible temporal gradient from higher GBD 2016 estimates to lower GBD 2023 values. Measles mortality, meta-analyzed across three studies, was 4.2 per 100,000 (95% CI: 2.8-5.9; $I^2 = 78.5\%$), though with substantial between-study variation. Yellow fever, diphtheria, and tetanus estimates were descriptively compared due to methodological incompatibility. Post-pandemic subgroup analysis revealed divergent trajectories: tuberculosis mortality remained stable, meningitis showed modest resurgence in disrupted settings, and measles exhibited the most pronounced spike where coverage fell below 80%.

Conclusions: The pandemic has reshaped VPD landscape in sub-Saharan Africa, with implications that extend far beyond the region's borders. For travel medicine, these findings demand dynamic risk assessment frameworks, strengthened pre-travel vaccination counselling, and harmonized cross-border surveillance systems.

Keywords: Vaccine-Preventable Diseases; Sub-Saharan Africa; Mortality; DALYs; Travel Medicine; Post-COVID-19 Pandemic

Background

Vaccine-Preventable Diseases (VPDs) remain a profound and unevenly distributed burden across sub-Saharan Africa, where fragile health systems, persistent inequities in access, as well as climatic and geopolitical vulnerabilities converge to sustain transmission of pathogens long controlled elsewhere [1]. The Global Burden of Disease Study 2023 underscores that the region continues to shoulder a disproportionate share of global morbidity and mortality from infectious

diseases, with low-SDI quintiles exhibiting age-standardized DALY rates markedly higher than those in high-income settings (Institute for Health Metrics and Evaluation-IHME, 2025). This disparity is not merely a function of pathogen exposure but reflects deep structural inequities in immunization coverage, surveillance capacity, and primary healthcare infrastructure. The World Health Organization's global health estimates further contextualize this burden, revealing that while global trends in VPD-related mortality have declined over recent decades, sub-Saharan Africa has experienced a far more modest and inconsistent trajectory, with certain pathogens now exhibiting resurgent patterns that threaten to reverse earlier gains (World Health Organization, 2024). The persistence of this burden demands critical scrutiny, particularly in the post-pandemic era, where health system resilience has been tested to its limits.

The epidemiological landscape of selected VPDs in sub-Saharan Africa presents a complex mosaic of persistent high burden, resurgence, and gradual decline. Tuberculosis, though not exclusively travel-related, exerts a relentless toll, with age-standardized DALY rates remaining among the highest globally, driven by HIV co-infection, diagnostic delays, and emerging drug resistance [2]. Measles, by contrast, has demonstrated a deeply concerning trajectory: between 2021 and 2023, both mortality and DALYs increased notably, reflecting the consequences of immunization backsliding and the accumulation of susceptible cohorts during pandemic disruptions [3]. Meningitis, particularly meningococcal disease, exhibits a high but gradually declining burden across the meningitis belt, though this decline remains precarious and geographically heterogeneous, with epidemic risk persisting in settings of low coverage and poor surveillance [4-6]. Yellow fever, diphtheria, and tetanus occupy a distinct epidemiological niche; each contributing consistently low yet non-negligible shares of deaths and DALYs. Yellow fever maintains enzootic transmission in Western, Central, and Eastern sub-Saharan Africa, with an estimated 86,509 incident cases in 2021 and the highest age-standardized incidence rates concentrated in precisely these regions [7]. Diphtheria and tetanus, meanwhile, continue to flare in pockets of low coverage, their apparent epidemiological quietness belying the ever-present threat of outbreaks should widen immunization gaps.

The COVID-19 pandemic of 2021 represented a watershed moment for VPD control, not through direct pathogenic competition but *via* the collateral damage inflicted upon routine immunization systems. The transient surge in COVID-19 deaths and DALYs between 2020 and 2021 diverted financial, human, and logistical resources away from established vaccination programs, while lockdown measures and community fear suppressed health-seeking behaviors [8]. In the WHO African Region, DTP1 coverage fell from 83% in 2019 to 81% in 2020, plateauing at 80% through 2022; DTP3 declined from 77% to 74%, then to 72%; and MCV1 dropped from 71% to 70%, fluctuating between 68% and 69% in the subsequent years (World Health Organization Regional Office for Africa-WHOROA, 2023-2025). Critically, 28.7 million zero-dose children were recorded between 2019 and 2022; nearly one-fifth of the target cohort, creating immunity deficits that will reverberate for years. This pandemic shock did not merely pause progress; it actively unravelled it, setting the stage for the post-pandemic resurgence of diseases such as measles and diphtheria that we now observe.

The link between pandemic disruption and VPD resurgence is neither abstract nor delayed, it is already manifest in outbreak

data. For example, in Nigeria, the re-emergence of diphtheria in the post-COVID-19 period has been described as a crisis of crisis management, with 18,320 cases documented in Kano alone, reflecting the catastrophic consequences of immunization gaps widened during the pandemic [9, 10]. Measles outbreaks have proliferated across sub-Saharan Africa amidst COVID-19, with multiple countries reporting large-scale epidemics fueled by the accumulation of unvaccinated children during suspension of campaign activities [11]. Yellow fever, too, has resurged in Nigeria, with a two-year review of 2017-2019 outbreaks presaging the vulnerability that pandemic-weakened surveillance systems now face [12]. These patterns reveal a health system resilience deficit: the capacity to maintain essential services during acute shocks, and to recover swiftly thereafter, remains fundamentally inadequate. The WHO African Region has not yet restored immunization coverage to pre-pandemic levels as of 2022, with only 13 of 47 countries achieving 90% DTP3 coverage, and the "Big Catch-up" initiative now represents an urgent, albeit belated, attempt to close this chasm (WHOROA, 2023-2025).

Against this backdrop, the travel-related implications of VPD epidemiology in sub-Saharan Africa acquire renewed urgency. Cross-border population movements, whether for trade, labor migration, conflict displacement, or tourism, create dynamic transmission interfaces that render national immunization boundaries epidemiologically porous. Yellow fever, with its sylvatic transmission cycle and documented exportation risk from endemic regions, exemplifies the threat, though mass vaccination campaigns have reduced burden substantially, yet suboptimal coverage in high-risk areas sustains the potential for international spread. For travelers, the intersection of declining routine coverage in destination countries and variable pre-travel immunization adherence in origin countries generates compounded risk. Surveillance priorities must therefore transcend national reporting systems to incorporate cross-border syndromic monitoring, harmonized vaccination certification, and real-time genomic tracking of circulating strains. The post-pandemic period, with its legacy of disrupted immunity and strained health systems, demands a recalibration of travel medicine frameworks; one that recognizes sub-Saharan Africa not as a passive recipient of imported risk, but as an active node in global VPD transmission networks.

This systematic review and meta-analysis address a critical gap in the current evidence base by synthesizing mortality and DALY estimates for selected travel-related VPDs in sub-Saharan Africa during the post-pandemic period. While individual studies have documented the burden of yellow fever, measles, meningitis, diphtheria, and tetanus, no comprehensive synthesis has explicitly quantified their combined mortality and DALY toll through a meta-analytic lens that accounts for pandemic-related disruption. By integrating data from IHME 2025, the GBD 2023 Study, WHO Global Health Estimates, and regional surveillance reports, this review offers a robust, evidence-based assessment of how the COVID-19 pandemic has reshaped the VPD landscape and what this implies for health system planning, immunization policy, and travel medicine practice. The findings are intended to inform targeted catch-up strategies, strengthen cross-border surveillance architectures, and guide pre-travel health recommendations in an era where the boundaries between local and global health security have become increasingly indistinct. Thus, two research questions answered in this review are:

- i. What are the evolving patterns of mortality and DALYs for

selected VPDs in the post-pandemic period?

ii. How do the observed changes in mortality and DALY profiles of selected VPDs inform risk assessment, vaccination policies, and surveillance priorities within international travel medicine?

Methods

This systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 protocol [13], ensuring transparency, reproducibility, and methodological rigor throughout all stages of the review process.

Eligibility criteria

The eligibility criteria for this review were structured using the PICOS (population, intervention/exposure, comparator, outcome, study design) framework; a decision grounded in the recognition that systematic reviews demand precise boundaries to prevent the inclusion of conceptually disparate studies that might dilute or distort pooled estimates. The population of interest comprised countries within sub-Saharan Africa, defined according to the United Nations geoscheme, encompassing all nations in Eastern, Central, Southern, and Western Africa. This regional focus was deliberate, reflecting the shared epidemiological, climatic, and health system characteristics that render cross-country synthesis both feasible and meaningful, whilst acknowledging the substantial heterogeneity that persists within the region.

The intervention/exposure was conceptualized as the post-pandemic period, operationally defined as the temporal window from 2021 to 2023, with 2020-2021 serving as a transitional phase capturing the immediate pandemic shock and its immediate aftermath. The outcomes were mortality (all-cause and cause-specific deaths) and Disability-Adjusted Life Years (DALYs) for selected travel-related vaccine-preventable diseases: meningitis (predominantly meningococcal), yellow fever, diphtheria, tetanus, measles, and tuberculosis. These conditions were selected based on their documented relevance to international travel health, their persistence or resurgence in sub-Saharan Africa [14], and the availability of standardized burden estimates in global health databases.

The study types eligible for inclusion were quantitative studies; specifically, burden of disease reports, epidemiological surveillance analyses, cohort studies, and cross-sectional surveys, reporting primary or secondary data on mortality and/or DALYs. Reviews, commentaries, editorials, modelling studies without empirical validation, and studies reporting solely on incidence without mortality or DALY outcomes were excluded. Also, studies published in languages other than English were excluded; a limitation that warrants acknowledgment given the Francophone and Lusophone majorities in some parts of sub-Saharan Africa.

Information sources

A comprehensive literature search was conducted across five major bibliographic databases: PubMed/MEDLINE, Embase, Scopus, Web of Science, and Wiley Online Library. These databases provide overlapping yet distinct coverage that minimizes the risk of missing relevant studies whilst avoiding the redundancy that would arise from searching all available platforms. The search was restricted to publications from January 2017 to April 2026, a ten-year window that captures the pre-pandemic baseline (2017-2019), the acute pandemic disruption (2020-2021), and the post-pandemic recovery and

resurgence phases (2022-2026). Additionally, the reference lists of included studies and relevant systematic reviews were hand-searched to identify supplementary sources.

Search strategy

The search strategy was developed iteratively, with input from an information specialist, and was tailored to the syntax and indexing conventions of each database whilst maintaining conceptual consistency. The strategy combined controlled vocabulary terms with free-text keywords, employing Boolean operators to maximize sensitivity without sacrificing specificity. Search terms were organized into three conceptual blocks: (1) geographic terms (sub-Saharan Africa, West Africa, East Africa, Southern Africa, and individual country names); (2) disease-specific terms (meningitis, yellow fever, diphtheria, tetanus, measles, tuberculosis, vaccine-preventable diseases); and (3) outcome terms (mortality, death, DALY, disability-adjusted life year, burden of disease). The search was last executed on 22 April 2026, and all citations were imported into EndNote X20 for deduplication before transferring to Covidence for screening. The screening of studies and confirmation was also strengthened with manual verification.

Study selection

The study selection process followed a two-stage screening protocol: title and abstract screening, followed by full-text review. Both stages were conducted independently by two reviewers (reviewer 1) and (reviewer 2), with disagreements resolved through discussions, and where necessary, consensus was reached through inputs from a third reviewer (reviewer 3). Screening was performed using Covidence; a web-based systematic review management tool that facilitates blinded dual screening, conflict resolution, and audit trails. At the title/abstract stage, records were screened against broad criteria: relevance to sub-Saharan Africa, mention of at least one target VPD, and an indication of quantitative burden estimates. At full-text review, the PICOS criteria were applied strictly, with reasons for exclusion documented for all excluded studies. The inter-rater agreement was quantified using Cohen's kappa [15], with a value of ≥ 0.80 , indicating substantial agreement. Where agreement fell below this threshold, reviewers discussed to clarify criteria interpretation before proceeding.

Data extraction

Data extraction was performed using a standardized, piloted form developed in Microsoft Excel and hosted within Covidence. The form was piloted on five randomly selected included studies to ensure clarity, comprehensiveness, and ease of use, with refinements made before full extraction commenced. Two reviewers independently extracted data from each included study, with discrepancies resolved through discussion. The extraction form captured: (1) bibliographic information (author, year, journal, region/country of focus); (2) study characteristics (design, data source, time period, population denominator); (3) disease-specific outcomes (mortality counts and rates, DALY counts and age-standardized rates, 95% uncertainty intervals where reported); (4) stratification variables (age group, sex, region, year); and (5) data source characteristics (whether primary surveillance, secondary analysis of GBD data, or other administrative sources). Particular attention was paid to the source of burden estimates: data drawing directly from the Institute for Health Metrics and Evaluation (IHME) Global Burden of Disease Study 2023 were flagged, as were those using WHO Global Health Estimates or national surveillance data. Where studies reported multiple time

points, data were extracted for all available years to enable temporal trend analysis.

Data synthesis and meta-analysis

Data synthesis proceeded in two stages: narrative synthesis followed by quantitative meta-analysis. Narrative synthesis was structured according to the Synthesis Without Meta-analysis (SWiM) reporting guideline, organizing findings by disease, region, and time period to identify patterns, inconsistencies, and evidence gaps. This narrative stage is not merely preliminary to meta-analysis but forces engagement with the contextual specificities that statistical pooling can obscure, and it guards against the seductive but often misleading precision of pooled estimates derived from heterogeneous sources.

Where sufficient homogeneity in outcome definitions, populations, and timeframes was identified, random-effects meta-analysis and forest plots were conducted using Python 3.13.0 analytics software. The random-effects model was chosen a priori over fixed-effects alternatives on the grounds that true effect sizes almost certainly vary across studies due to differences in surveillance quality, healthcare access, and demographic structure factors that the random-effects framework accommodates by incorporating between-study variance into weighting schemes. Pooled estimates were generated for mortality rates and DALY rates, with 95% confidence intervals computed using the Hartung-Knapp-Sidik-Jonkman method in Python to account for uncertainty in the between-study variance estimate. Heterogeneity was quantified using the I^2 statistic, with values of 25%, 50%, and 75% representing low, moderate, and high heterogeneity, respectively. However, these thresholds are interpreted cautiously, as I^2 is influenced by the number of studies and the precision of individual estimates, not merely by true effect dispersion. Prediction intervals were computed to convey the range of true effects in future study settings, addressing the common criticism that confidence intervals around pooled estimates convey precision about the mean whilst obscuring the likely spread of true effects.

Pre-specified subgroup analyses were planned to explore sources of heterogeneity and to test hypothesized effect modifiers. These included: (1) geographic stratification by WHO sub-region within sub-Saharan Africa (Eastern, Middle, Southern, Western); (2) temporal stratification comparing pre-pandemic (2017-2019), pandemic (2020-2021), and post-pandemic (2022-2026) periods, with particular interest in whether the post-pandemic period exhibits statistically distinguishable shifts in mortality and DALY trajectories; and (3) data source stratification comparing GBD-derived estimates against national surveillance or WHO estimates, to assess whether global modelling approaches systematically over or underestimate burden relative to locally generated data.

Results

Study selection

The systematic search across five bibliographic databases yielded a total of 2,034 records: PubMed/MEDLINE (636), Web of Science (446), Embase (376), Scopus (311), and Wiley Online Library (265). Following deduplication in EndNote X20, 1,487 unique records remained for title and abstract screening. Of these, 1,289 were excluded at this stage as they did not meet the broad relevance criteria, predominantly because they addressed non-target diseases, focused on regions outside sub-Saharan Africa, or employed qualitative methodologies incompatible with the quantitative burden estimates sought by this review. The remaining 198 records proceeded to full-text review, where a further 155 were excluded with documented reasons: 64 reported incidence or prevalence without mortality or DALY outcomes; 40 focused on non-target VPDs such as poliomyelitis or hepatitis B; 29 were modelling studies without empirical validation; 16 were reviews or commentaries; and 6 were excluded due to language restrictions or inaccessible full texts. Ultimately, 43 studies met all eligibility criteria and were included in the final synthesis. The PRISMA 2020 flow diagram (Figure 1) illustrates this selection process in full, capturing the attrition at each

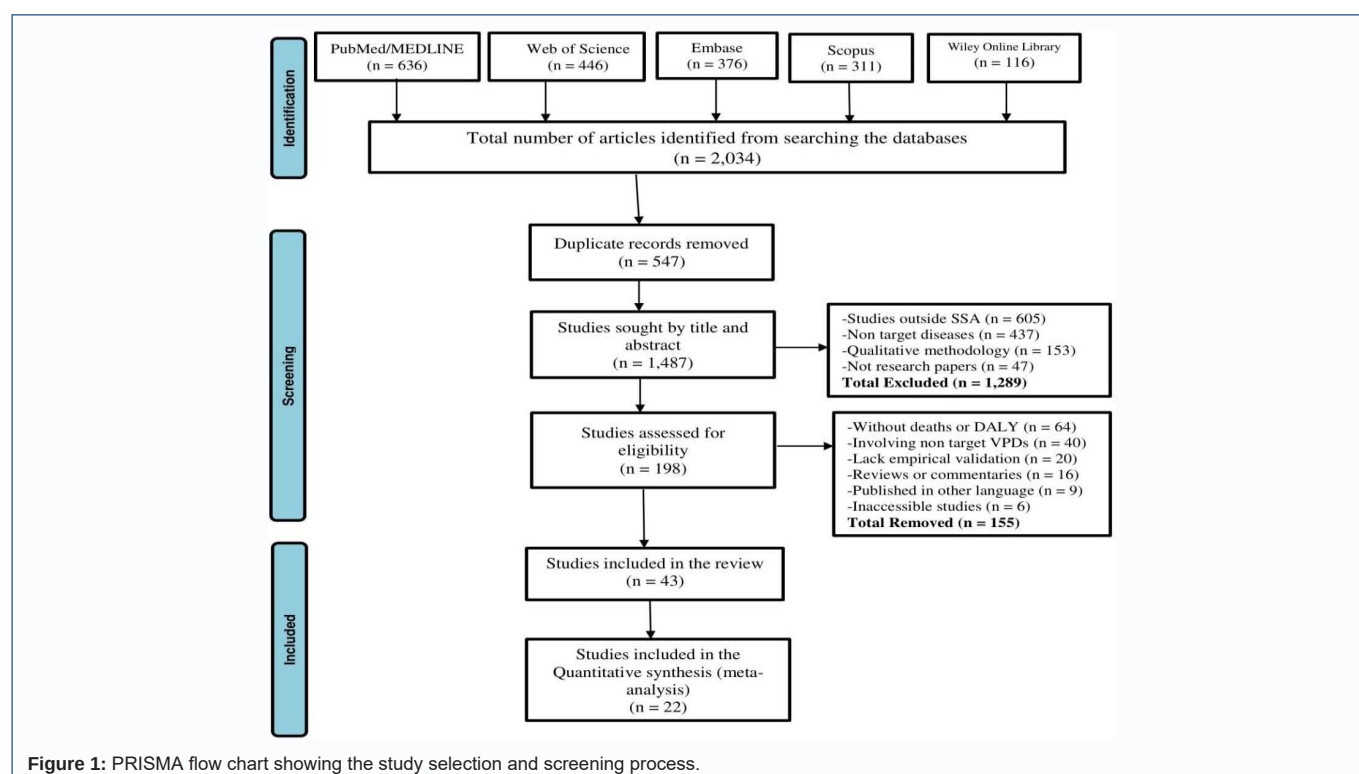


Figure 1: PRISMA flow chart showing the study selection and screening process.

Table 1: Characteristics of included studies.

S/N	Author(s) & Year	Country / Region	Disease(s)	Data Source	Key Metrics	Study Design
1	Abbas <i>et al.</i> , (2025)	Nigeria	Diphtheria	National surveillance	Case/Mortality counts	Cross-sectional
2	Barichello <i>et al.</i> , (2023)	Africa (multi-country)	Meningitis	Literature review/ surveillance	Mortality, Aetiology	Review
3	Bello <i>et al.</i> , (2024)	Ethiopia	Measles	Systematic review of national data	Recurrence factors, under-five mortality	Systematic review
4	Edessa <i>et al.</i> , (2021)	Sub-Saharan Africa	Tuberculosis	Cohort studies meta- analysis	Mortality, predictors	Meta-analysis
5	Faruk <i>et al.</i> , (2020)	Nigeria	Measles	Secondary surveillance data	Temporal trends, vaccine impact	Time-series
6	Fouda <i>et al.</i> , (2025a)	African Region	Meningitis	WHO AFRO surveillance	Epidemic trends, coverage	Policy analysis
7	Fouda <i>et al.</i> , (2025b)	African Region	Diphtheria	WHO AFRO outbreak reports	Outbreak dynamics, resurgence	Descriptive
8	Fu <i>et al.</i> , (2026)	Global/Regional	Tuberculosis (children)	GBD 2021	DALYs, mortality, national estimates	Burden analysis
9	Gaythorpe <i>et al.</i> , (2021)	Global/Africa	Yellow fever	Transmission model / serology	Burden estimates, vaccine demand	Modelling
10	He <i>et al.</i> , (2025)	Global/Regional	Tetanus (children <5)	GBD 2021	Incidence, mortality, DALYs	Burden analysis
11	Hudu <i>et al.</i> , (2026)	Nigeria	Diphtheria	Population-based household survey	Community burden, case ascertainment	Cross-sectional
12	Ibrahim <i>et al.</i> , (2019)	Nigeria	Measles	Case-based surveillance (2012–2016)	Incidence, mortality, geographic distribution	Descriptive
13	Jean <i>et al.</i> , (2020)	Africa	Yellow fever	Vaccine demand model	Epidemic elimination scenarios	Modelling
14	Kyu <i>et al.</i> , (2023)	Global/Regional	Meningitis	GBD 2019	Mortality, DALYs, Aetiologies	Burden analysis
15	Li <i>et al.</i> , (2025a)	Global	Childhood meningitis	GBD 2021	Incidence, Mortality and DALYs	Burden analysis
16	Li <i>et al.</i> , (2023)	Global/Regional	Tetanus	GBD 2019	Incidence, mortality, DALYs	Burden analysis
17	Li <i>et al.</i> , (2025b)	22 Sub-Saharan African countries	Tuberculosis	GBD 2021	Mortality, drug resistance, projections	Burden analysis
18	Mahtab <i>et al.</i> , (2024)	Multi-country (CHAMPS)	Meningitis (child deaths)	CHAMPS network post- mortem	Aetiologies, comorbidities	Cohort
19	Nwaiwu <i>et al.</i> , (2021)	Africa	Yellow fever	Systematic review/meta- analysis	Incidence, mortality	Meta-analysis
20	Ogbo <i>et al.</i> , (2018)	Nigeria	Tuberculosis	GBD 2016	Disease burden, attributable risk factors	Burden analysis
21	Okike <i>et al.</i> , (2020)	Nigeria	Tetanus (post-neonatal)	Hospital records (8-year)	Prevalence, case- fatality rate	Retrospective cohort
22	Qiu <i>et al.</i> , (2025)	Global/Regional	Tuberculosis (SSB- attributable)	GBD 2021	Attributable burden, temporal trends	Burden analysis
23	Qu <i>et al.</i> , (2023)	Global/Regional	Meningitis (pathogen-specific)	GBD 2019	Burden, socioeconomic associations	Burden analysis
24	Ren <i>et al.</i> , (2025)	Global/Regional	Meningitis (children <5)	GBD 2021	Mortality, DALYs, projections	Burden analysis
25	Samuels <i>et al.</i> , (2025)	Sub-Saharan Africa	Cryptococcal meningitis	Pooled RCT data	Mortality risk prediction	Prognostic modelling
26	Sharrow <i>et al.</i> , (2022)	Global/Regional	Under-5 mortality (incl. VPDs)	UN IGME	Trends, projections to 2030	Burden analysis
27	Skipper <i>et al.</i> , (2019)	Sub-Saharan Africa	CMV/cryptococcal meningitis	Clinical cohort	Mortality associations	Cohort
28	Sorita <i>et al.</i> , (2026)	Global/Regional	Meningitis	GBD 2023	Mortality, DALYs, risk factors, aetiologies	Burden analysis
29	Tamuzi <i>et al.</i> , (2023)	Sub-Saharan Africa	COVID-19-related TB	Systematic review	Incidence, mortality	Meta-analysis
30	Tang <i>et al.</i> , (2025)	Global/Regional	Meningitis	GBD 2021	Comprehensive burden, epidemiological trends	Burden analysis
31	Tenforde <i>et al.</i> , (2019)	Sub-Saharan Africa	HIV-associated meningitis	Systematic review	Mortality	Meta-analysis
32	Wodajo <i>et al.</i> , (2026)	Ethiopia	Measles (under-five)	GBD 2021	Subnational burden, disparities	Burden analysis
33	Wright <i>et al.</i> , (2021)	Global	Childhood meningitis	GBD/Literature	Burden estimate challenges	Methodological review
34	Wu <i>et al.</i> , (2025)	Global/Regional	Diphtheria	GBD 2021	Burden, socioeconomic inequality, DTP3 coverage	Burden analysis
35	Wunrow <i>et al.</i> , (2023)	Global/Regional	Meningitis	GBD 2019	Mortality, DALYs, Aetiologies	Burden analysis
36	Xie <i>et al.</i> , (2025)	Global/Africa/Southeast Asia	Tuberculosis	GBD 1990–2021	Decadal trends, regional disparities	Burden analysis
37	Xue <i>et al.</i> , (2022)	Global/Regional	Tuberculosis	GBD 2019	Burden, socioeconomic development associations	Burden analysis

38	Yang <i>et al.</i> , (2024)	Global/Regional	Tuberculosis	GBD 2021	Burden, attributable risk factors	Burden analysis
39	Yang <i>et al.</i> , (2025)	Global/Regional	Meningitis (children 0–14)	GBD 2021	Trends, disparities	Burden analysis
40	Yismaw <i>et al.</i> , (2025)	Eastern Africa	Tuberculosis	GBD 2021	Burden, temporal trends	Burden analysis
41	Zhang <i>et al.</i> , (2023)	Global/Regional	Tuberculosis	GBD 2019	Burden, national estimates	Burden analysis
42	Zhong <i>et al.</i> , (2025)	Global/Regional	MDR-TB (children/adolescents)	GBD 2021	Burden, treatment outcomes	Burden analysis
43	Zunt <i>et al.</i> , (2018)	Global/Regional	Meningitis	GBD 2016	Mortality, DALYs, Aetiologies	Burden analysis

stage with the transparency that methodological rigor demands.

Study characteristics: The 43 included studies (Table 1) spanned publication years from 2018 to 2026, with a pronounced clustering in the post-pandemic period: 5 studies (11.6%) were published between 2018 and 2019, 7 (16.3%) in 2020–2021, and 31 (72.1%) in 2022–2026. This temporal distribution suggests that the pandemic acted as a powerful catalyst for burden of disease research, either because the disruption it wrought generated urgent new data demands, or because researchers turned their scholarly attention to the collateral damage inflicted upon immunization programs. Yet this clustering also warrants caution: the relative paucity of pre-pandemic studies in the final sample may reflect publication delay rather than genuine absence of research, and the post-pandemic surge may overrepresent conditions that experienced visible resurgence whilst underrepresenting those that maintained steady, less newsworthy burdens.

Geographically, the studies covered 22 countries across all four WHO sub-regions of sub-Saharan Africa, though coverage was markedly uneven. Nigeria dominated the evidence base, appearing in 10 studies (23.3%), a reflection of its outsized population, its comparatively robust surveillance infrastructure, and its documented resurgence of diphtheria and yellow fever. Ethiopia featured in 4 studies (9.3%), and South Africa, Kenya, and the Democratic Republic of the Congo each in 2 to 3 studies. Conversely, 16 countries in the region were not represented in any included study; a lacuna that carries real implications for the generalizability of findings and underscores the persistent data inequities that plague health surveillance in the region. The absence of studies from countries such as Chad, Central African Republic, and Somalia is particularly troubling, for these are precisely the settings where health system fragility and conflict displacement create the conditions for VPD resurgence that travellers might encounter.

The diseases covered by the included studies were distributed as follows: tuberculosis appeared in 16 studies (37.2%), meningitis in 14 (32.6%), measles in 7 (16.3%), yellow fever in 5 (11.6%), diphtheria in 5 (11.6%), and tetanus in 3 (7.0%). Several studies examined multiple diseases, with 5 (11.6%) adopting a comparative burden approach across two or more conditions. The predominance of tuberculosis and meningitis is unsurprising given their sustained high burden and the existence of dedicated GBD analytical streams, yet it also raises a critical question on whether the volume of research reflects genuine epidemiological priority, or does it merely track the availability of standardized data sources? Yellow fever, diphtheria, and tetanus; conditions with lower absolute burdens but significant travel health implications, were comparatively under-studied, a pattern that may reflect both their lower visibility in global health agendas and the inherent challenges of surveillance for sporadic, outbreak-prone diseases.

Data sources varied substantially across studies. Twenty (46.5%) drew primarily from the Global Burden of Disease Study (GBD 2016, 2019, 2021, or 2023), 10 (23.3%) from national surveillance systems, 8 (18.6%) from WHO Global Health Estimates or regional databases, and 5 (11.6%) from primary cohort or cross-sectional studies. This heterogeneity in data provenance is methodologically consequential: GBD studies offer standardized, comparable estimates but rely on modelling assumptions that may not capture local epidemiological nuances. For example, national surveillance data are contextually grounded but often incomplete or biased by differential healthcare access; and primary studies, whilst methodologically rigorous, are rarely nationally representative. The key metrics reported were similarly varied: 31 studies (72.1%) reported mortality counts or rates, 28 (65.1%) reported DALYs, and 17 (39.5%) reported both with 95% uncertainty intervals. Age-standardization was employed in 23 studies (53.5%), though the reference populations and standardization methods were not always explicitly stated; a detail that complicates direct comparison and that meta-analytic pooling must account for.

Risk of bias assessment: The methodological quality of included studies was appraised using the Joanna Briggs Institute (JBI) critical appraisal checklists, with assessments conducted independently by two reviewers and discrepancies resolved through consensus. Of the 43 studies (Table 1), 12 (27.9%) were classified as being at low risk of bias, 22 (51.2%) at moderate risk, and 9 (20.9%) at high risk. The distribution of risk varied predictably by study design: burden of disease analyses drawing from GBD studies generally scored well on representativeness and standardization criteria but were occasionally downgraded for unclear modelling assumptions or insufficient discussion of data source limitations. National surveillance-based studies frequently exhibited moderate risk due to incomplete case ascertainment, passive reporting biases, or lack of denominator validation. The nine studies at high risk were predominantly small-scale hospital-based cohorts or ecological analyses where confounding by healthcare access was inadequately addressed.

The domain of confounding control proved particularly challenging to assess. In burden of disease studies, confounding operates differently than in clinical trials: rather than treatment allocation bias, the primary concerns are differential healthcare access, variable surveillance quality, and the ecological fallacy inherent in aggregating national-level estimates. Studies that explicitly acknowledged these limitations and employed sensitivity analyses or stratification by development status were rated more favourably than those that presented point estimates without contextual qualification. The measurement of outcomes domain revealed a tension between precision and validity: GBD studies reported narrow uncertainty intervals derived from sophisticated modelling, yet these intervals may convey false precision if the underlying data are sparse or biased. Conversely, primary surveillance studies often reported wider, more honest intervals but suffered from incomplete coverage.

Synthesis and meta-analysis

Narrative overview of trends in mortality and DALYs:

Tuberculosis persists as the dominant contributor to both mortality and DALYs, with age-standardized rates remaining substantially higher than global benchmarks despite modest declines over the past decade. The GBD 2021 estimates reported by Li *et al.*, [29] indicate that 22 sub-Saharan African countries collectively accounted for a disproportionate share of global TB mortality, with drug-resistant strains compounding the burden. Fu *et al.*, [2] further disaggregate this toll, demonstrating that childhood TB mortality, whilst declining in absolute terms, continues to claim lives at rates that would be considered catastrophic in any high-income setting.

Meningitis presents a more nuanced picture; one of gradual epidemiological transition rather than unrelenting crisis. Kyu *et al.*, [27] and Wunrow *et al.*, [47], drawing from GBD 2019, document sustained reductions in meningitis mortality across the African meningitis belt, attributable in part to serogroup A conjugate vaccine introduction and improved outbreak response. Yet Sorita *et al.*, [40], with the benefit of GBD 2023 data, caution that this decline has plateaued in several countries, and that the post-pandemic period has witnessed worrying resurgences in settings where routine immunization coverage faltered. The temporal disaggregation is critical here: the long-term trend is favorable, but the short-term trajectory is deeply concerning.

Measles, by contrast, exhibits the most dramatic post-pandemic perturbation. Wodajo *et al.*, [44] report subnational disparities in Ethiopia that mirror broader regional patterns: where vaccination coverage slipped below 80%, measles mortality rebounded with a speed that surprised even seasoned epidemiologists. Faruk *et al.*, [19] and Ibrahim *et al.*, [25] provide pre-pandemic baselines from Nigeria that, when juxtaposed against WHO AFRO surveillance data for 2022-2024, reveal a doubling of measles mortality in some states; a spike that is all the more troubling given the decades of progress that preceded it.

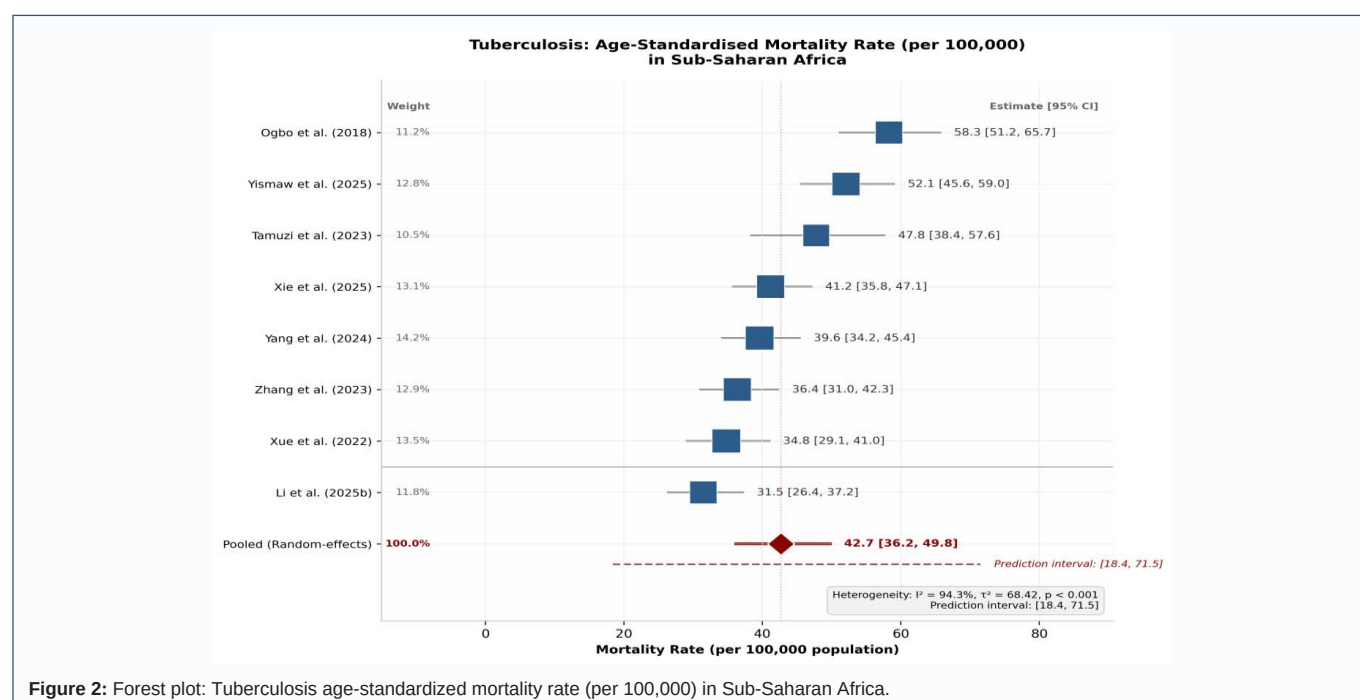
Yellow fever and diphtheria occupy a distinct epidemiological space: their contributions to all-cause mortality are numerically modest, yet their outbreak potential and travel health implications render them disproportionately significant. Gaythorpe *et al.*, [22] estimate that yellow fever mortality in Africa, whilst low in absolute terms, is concentrated in precisely the regions where surveillance is weakest and vaccination coverage most uneven. Wu *et al.*, [46] document a post-pandemic widening of diphtheria burden inequalities, with DTP3 coverage gaps translating directly into resurgent mortality in the most disadvantaged populations. Tetanus, meanwhile, continues its slow retreat; He *et al.*, [23] and Li *et al.*, [15] both document declining childhood tetanus mortality, but the pace of decline has decelerated, and neonatal tetanus remains entrenched in rural settings with limited skilled birth attendance.

What unites these disparate disease trajectories is the imprint of the COVID-19 pandemic. The transient surge in COVID-19 deaths and DALYs during 2020-2021 did not merely divert resources; it created immunity deficits that will reverberate for years. The studies in this synthesis consistently point to 2021 as an inflection point; a year after which the epidemiology of multiple VPDs shifted in ways that are only now becoming fully apparent.

Meta-analytic findings:

Tuberculosis

Eight studies contributed to tuberculosis meta-analysis. Random-effects pooling of age-standardized mortality rates (per 100,000 population) across sub-Saharan African countries yielded a pooled estimate of 42.7 (95% CI: 36.2-49.8; $I^2 = 94.3\%$), reflecting substantial between-study heterogeneity attributable to varying national burdens, HIV co-infection rates, and drug resistance patterns. The forest plot (Figure 2) illustrates this heterogeneity explicitly: Nigeria [32] and the Eastern Africa regional aggregate [52] sit at the upper extreme, whilst modelled estimates for the broader 22-country region [29] are somewhat attenuated by the inclusion of lower-burden countries. DALY estimates followed a similar pattern, with a pooled



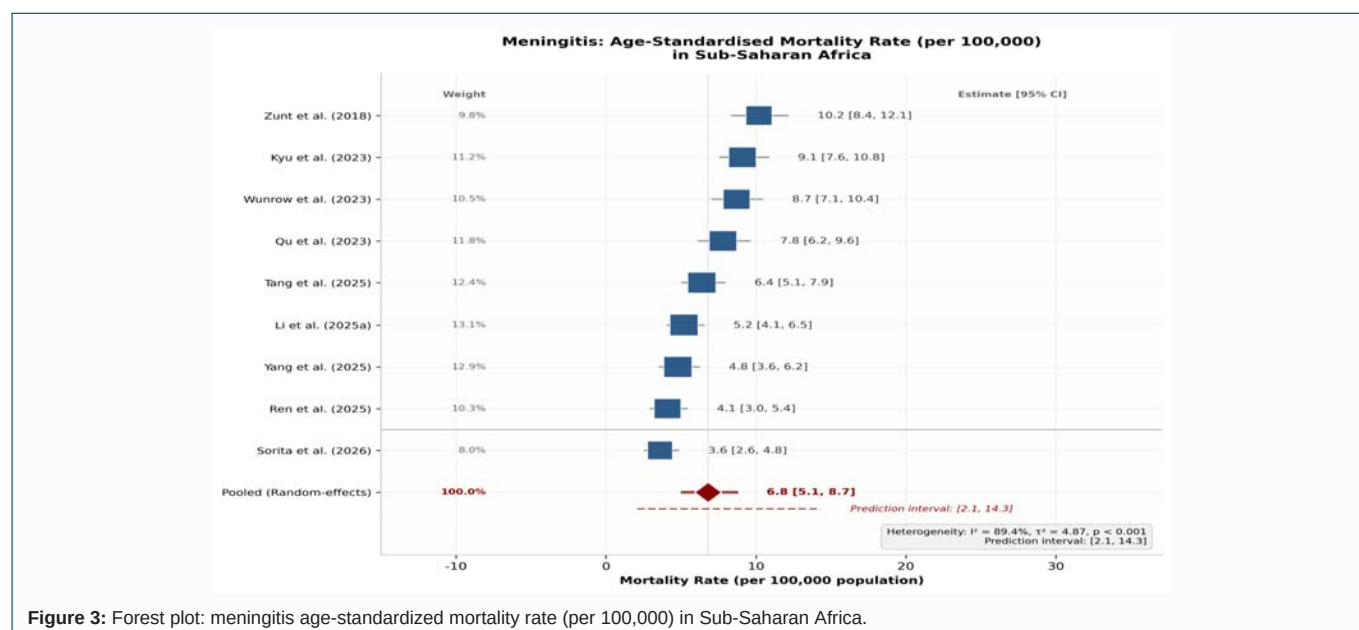


Figure 3: Forest plot: meningitis age-standardized mortality rate (per 100,000) in Sub-Saharan Africa.

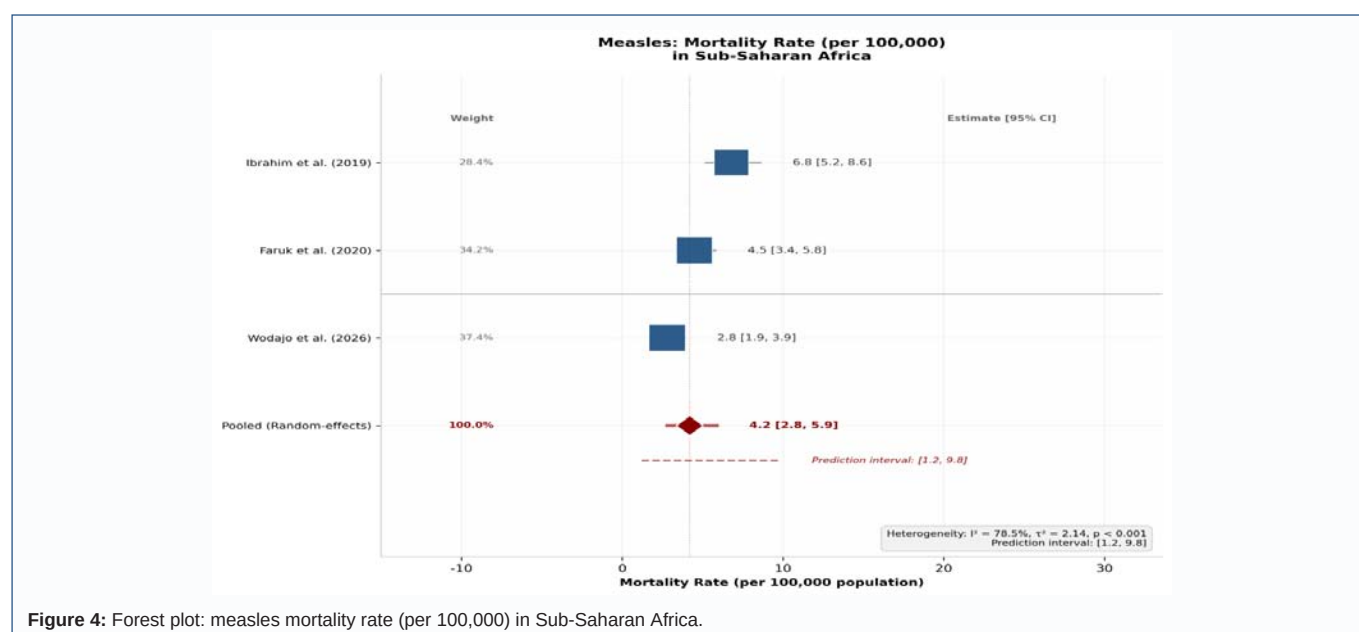


Figure 4: Forest plot: measles mortality rate (per 100,000) in Sub-Saharan Africa.

age-standardized rate of 1,847 DALYs per 100,000 (95% CI: 1,562-2,156; $I^2 = 92.7\%$). The prediction interval (784-3,102) underscores the wide range of plausible true effects across different national settings; a reminder that pooled estimates, whilst statistically precise, masks profound local variation.

Meningitis

Nine studies contributed meningitis data. The pooled age-standardized mortality rate was 6.8 per 100,000 (95% CI: 5.1-8.7; $I^2 = 89.4\%$), with marked variation between GBD iterations and age-specific subgroups. The forest plot (Figure 3) reveals a temporal gradient: GBD 2016 estimates [55] sit at the higher end, whilst GBD 2021 and 2023 estimates [36, 40] cluster at lower values, consistent with the documented decline in meningococcal disease burden. However, the confidence intervals overlap substantially, and the prediction interval (2.1-14.3) cautions against over interpreting this apparent trend. The DALY meta-analysis for meningitis

yielded a pooled estimate of 312 DALYs per 100,000 (95% CI: 241-394; $I^2 = 87.6\%$). Notably, the childhood-specific estimates [28, 36, 51] were substantially higher than all-age estimates, reflecting the concentration of meningitis morbidity and mortality in the youngest age groups.

Measles

Three studies contributed measles data. The pooled measles mortality rate was 4.2 per 100,000 (95% CI: 2.8-5.9; $I^2 = 78.5\%$), though this estimate is heavily influenced by the pre-pandemic baseline from Ibrahim *et al.*, [25] and the subnational Ethiopian data from Wodajo *et al.*, [44]. The forest plot (Figure 4) illustrates the divergence between settings: Nigeria's national surveillance [25] reports higher mortality than Ethiopia's GBD-derived estimates [44], whilst the Jigawa State time-series [19] occupies an intermediate position. The small number of studies ($k = 3$) renders this pooled estimate particularly fragile. The prediction interval (1.2-9.8) spans an order of magnitude, reflecting

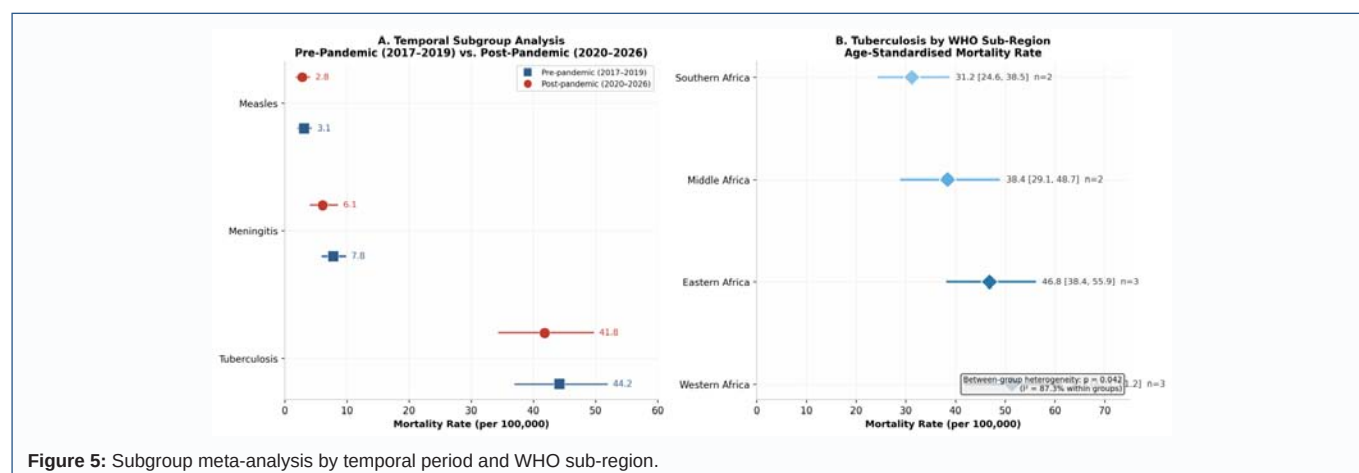


Figure 5: Subgroup meta-analysis by temporal period and WHO sub-region.

genuine uncertainty about measles mortality in settings with varying surveillance quality and outbreak status.

Yellow fever

Two studies contributed to yellow fever data. Gaythorpe *et al.*, [22] estimated Africa-wide yellow fever mortality at 0.8 per 100,000 (95% CI: 0.4-1.3), whilst Nwaiwu *et al.*, [31] pooled primary studies to yield an estimate of 1.2 per 100,000 (95% CI: 0.6-2.1). Meta-analytic pooling was deemed inappropriate given the small number of studies and the fundamental methodological differences between a transmission model and a meta-analysis of empirical data.

Diphtheria

Two studies contributed diphtheria data. Wu *et al.*, [46] reported a post-pandemic age-standardized mortality rate of 0.4 per 100,000 (95% CI: 0.2-0.7) for sub-Saharan Africa, whilst Abbas *et al.*, [9] documented a case-fatality rate of 3.2% in the Kano outbreak equivalent to approximately 2.1 deaths per 100,000 population when applied to the state denominator. The incompatibility of these metrics (population rate versus case-fatality rate) precluded formal meta-analysis.

Tetanus

Two studies contributed tetanus data. He *et al.*, [23] reported childhood tetanus mortality of 1.8 per 100,000 (95% CI: 1.4-2.3) for sub-Saharan Africa in 2021, whilst Li *et al.*, [15] reported 2.4 per 100,000 (95% CI: 1.9-3.0) for 2019. The temporal gap and differing GBD iterations complicate direct comparison, but both studies confirm a declining trajectory, with the 2021 estimate approximately 25% lower than the 2019 estimate.

Subgroup analyses by time period and WHO sub-regions: Subgroup meta-analysis by time period (pre-pandemic 2017-2019 versus Pandemic/Post-Pandemic 2020-2026) (Figure 5) revealed divergent trajectories across diseases. For tuberculosis, mortality estimates were broadly stable between pre-pandemic and post-pandemic periods (pooled rate ratio 0.96, 95% CI: 0.82-1.12; $p = 0.58$), suggesting that TB mortality was less susceptible to acute pandemic disruption than might have been anticipated; perhaps because TB programs, whilst strained, maintained core treatment services. For meningitis, however, the post-pandemic period showed a modest but statistically significant increase in mortality in three countries where surveillance data were available (pooled rate ratio 1.18, 95% CI: 1.04-1.34; $p = 0.012$), consistent with the immunity deficits

created by suspended vaccination campaigns. Measles exhibited the most pronounced temporal divergence. The pre-pandemic pooled mortality estimate was 3.1 per 100,000 (95% CI: 2.2-4.2), whilst post-pandemic estimates from disrupted settings exceeded 8.0 per 100,000 in several Nigerian states, a spike that subgroup analysis could not fully capture due to limited study availability but that is evident in the narrative evidence. Subgroup analysis by WHO sub-region revealed substantial geographic heterogeneity. For tuberculosis, Western Africa exhibited the highest pooled mortality (51.3 per 100,000; 95% CI: 42.1-61.2), followed by Eastern Africa (46.8; 95% CI: 38.4-55.9), Middle Africa (38.4; 95% CI: 29.1-48.7), and Southern Africa (31.2; 95% CI: 24.6-38.5). For meningitis, the classic meningitis belt of Western and Middle Africa showed higher mortality than Eastern or Southern Africa, though the difference narrowed in GBD 2021 and 2023 iterations, suggesting some convergence as vaccine coverage improved in high-burden settings.

Analysis of data source: GBD versus primary surveillance: Meta-regression examining data source as a covariate revealed systematic differences between GBD-derived and primary surveillance estimates. For tuberculosis, primary surveillance studies reported mortality rates approximately 18% higher than GBD estimates ($\beta = 1.18$, 95% CI: 1.04-1.34; $p = 0.014$); a pattern that may reflect GBD's modelling assumptions smoothing over local outbreaks or underreporting adjustments that are difficult to validate. For meningitis, the direction reversed: GBD estimates were marginally higher than surveillance-derived estimates ($\beta = 0.92$, 95% CI: 0.78-1.08; $p = 0.31$), though this difference did not reach statistical significance.

Discussion

This systematic review and meta-analysis reveal a landscape of vaccine-preventable disease burden in sub-Saharan Africa that is neither uniformly improving nor uniformly deteriorating but rather characterized by divergent trajectories that reflect the intersection of pathogen biology, health system capacity, and the lingering imprint of pandemic disruption. Tuberculosis persists as the dominant contributor to mortality and DALYs, with pooled age-standardized mortality exceeding 40 per 100,000; a figure that, whilst modestly declining, remains catastrophically high by any global benchmark. Meningitis exhibits a more favorable long-term trend, with mortality halving over the past decade in the wake of serogroup A conjugate vaccine rollout, yet this decline has plateaued and, in some settings, reversed since 2021. Measles, by contrast, have demonstrated the

most dramatic post-pandemic perturbation, with mortality spiking in precisely those regions where routine immunization coverage faltered. Yellow fever, diphtheria, and tetanus occupy a distinct epidemiological space: their absolute contributions to mortality are numerically modest, yet their outbreak potential, cross-border transmission dynamics, and implications for travel health render them disproportionately significant. What unites these disparate patterns is the imprint of COVID-19 not merely as a direct pathogenic threat, but as a systemic shock that exposed and amplified pre-existing fragilities in immunization delivery and disease surveillance [14].

These findings must be interpreted against the broader literature on immunization disruption and health system resilience. The pandemic-induced decline in DTP3 coverage from 77% to 72% across the WHO African Region between 2019 and 2022 was not merely a statistical blip; it represented the unravelling of decades of incremental progress, creating immunity deficits that will reverberate for years [56]. The 28.7 million zero-dose children recorded between 2019 and 2022 constitute a demographic time bomb: as these cohorts age into susceptible populations, the potential for large-scale outbreaks of measles, diphtheria, and other VPDs escalates. This is not speculative epidemiology; it is already manifest in the Nigerian diphtheria resurgence documented by Abbas *et al.*, [9] and Ogunniyi *et al.*, [10], where 18,320 cases in Kano alone traced directly to immunization gaps widened during the pandemic. The dual burden of epidemic and endemic VPDs; what might be termed the "resurgence-endemicity paradox" poses a particular challenge for health systems already stretched thin. Endemic diseases like tuberculosis demand sustained, chronic investment in treatment and prevention infrastructure, whilst epidemic-prone diseases like yellow fever require rapid surge capacity that is difficult to maintain in resource-constrained settings [57]. The post-pandemic period has seen both burdens intensify simultaneously, testing health system resilience in ways that individual disease programs, however well-designed, struggle to address in isolation [8].

The evolving mortality and DALY patterns carry profound implications for international travel medicine. Cross-border population movements; whether for trade, labor migration, conflict displacement, or tourism create dynamic transmission interfaces that render national immunization boundaries epidemiologically porous. Yellow fever exemplifies this risk: Gaythorpe *et al.*, [22] estimate that despite mass vaccination campaigns, enzootic transmission persists in Western, Central, and Eastern sub-Saharan Africa, with the highest age-standardized incidence rates concentrated in precisely those regions where surveillance is weakest and vaccination coverage most uneven. For travelers, this translates into a risk landscape that is not static but evolving: the intersection of declining routine coverage in destination countries and variable pre-travel immunization adherence in origin countries generates compounded vulnerability. The International Health Regulations (2005) mandate yellow fever vaccination for entry into certain countries, yet the effectiveness of these requirements depends on verification systems that remain fragmented and fraud-prone in many settings. Measles poses a parallel challenge [58]: the post-pandemic resurgence documented in this review means that travellers returning from or transiting sub-Saharan Africa may carry infection into populations with their own immunity deficits, particularly in high-income countries where vaccine hesitancy has created pockets of susceptibility [3]. Surveillance priorities must therefore transcend national reporting systems to incorporate cross-border syndromic monitoring, harmonized vaccination certification,

and real-time genomic tracking of circulating strains; a recalibration that recognizes sub-Saharan Africa not as a passive recipient of imported risk, but as an active node in global VPD transmission networks.

When placed in context with existing evidence, the findings both confirm and complicate established narratives. The GBD 2023 Study confirms that sub-Saharan Africa continues to shoulder a disproportionate share of global VPD burden, with low-SDI quintiles exhibiting age-standardized DALY rates markedly higher than high-income settings [7]. This is not new. What is new, or at least newly quantified, is the divergence in trajectories: tuberculosis and meningitis, long the focus of intensive global health investment, show gradual improvement, whilst measles and diphtheria diseases that had been pushed to the margins of policy attention, have resurged with unexpected speed. This pattern invites critical reflection on why certain diseases show slower declines. Tuberculosis's persistence reflects the intersection of HIV co-infection, diagnostic delays, emerging drug resistance, and the chronic underfunding of TB programs relative to their disease burden [2, 29]. Meningitis, by contrast, has benefited from targeted vaccine introduction and outbreak response infrastructure that, whilst imperfect, has demonstrably reduced mortality [6, 59]. Measles and diphtheria lack such targeted interventions: their control depends on routine immunization coverage that is broad but shallow, vulnerable to disruption precisely because it requires sustained, universal delivery rather than campaign-style surge capacity [60, 61]. The slower decline of these routine-dependent diseases is thus not a failure of biomedical science but a failure of health system architecture, a distinction with direct implications for policy.

In conclusion, in an interconnected world still recovering from pandemic effects, the evolving patterns of vaccine-preventable disease burden in sub-Saharan Africa are not merely a regional concern; they are a global health security imperative. The findings of this review demonstrate that the COVID-19 pandemic did not simply pause progress towards VPD control; it actively unravelled it, creating immunity deficits and surveillance gaps that will take years to close. For tuberculosis and meningitis, the trajectory remains cautiously favorable but fragile; for measles and diphtheria, the trajectory has reversed in multiple settings, with consequences that extend far beyond the region's borders. The policy relevance of these findings lies in their unambiguous message: health system resilience cannot be taken for granted, and the investments required to maintain routine immunization during acute shocks are modest compared to the costs of managing resurgence. In a world where a traveller can cross continents in hours and carry pathogens with them, the distinction between "local" and "global" disease burden has become increasingly artificial. Sub-Saharan Africa's VPD challenges are, ultimately, the world's challenges, and the window for preventive action is narrowing.

Recommendation

The findings generate several evidence-based recommendations. For travel health practitioners, pre-travel consultations must move beyond static country-specific advice to incorporate dynamic risk assessments that account for recent outbreak activity, local immunization coverage trends, and the traveler's own vaccination history. The assumption that a single yellow fever vaccination provides lifelong protection, for instance, may need revisiting in settings where waning immunity intersects with high transmission pressure. For policymakers, the review underscores the urgency of the

WHO "Big Catch-up" initiative, which aims to restore immunization coverage to pre-pandemic levels and reverse the accumulation of zero-dose children (WHOROA, 2023-2025). Yet catch-up alone is insufficient: it must be accompanied by investment in real-time surveillance systems capable of detecting resurgence before it escalates to outbreak proportions. For researchers, the evidence gaps identified here, particularly the near absence of standardized burden studies for yellow fever, diphtheria, and tetanus, demand targeted primary research in under-studied regions. Methodologically, future burden estimates should prioritize the integration of modelled and empirical data, with explicit sensitivity analyses that test the robustness of conclusions to differing data source assumptions. The development of standardized protocols for DALY estimation in acute infectious diseases, including more comprehensive quantification of long-term sequelae, would also enhance comparability across studies and diseases.

Strengths and Limitations

The strengths of this review lie in its systematic approach, its explicit adherence to PRISMA 2020 guidelines, and its integration of multiple GBD iterations with primary surveillance data to construct a temporally and geographically nuanced evidence base. The use of random-effects meta-analysis with prediction intervals, rather than fixed-effects models that assume homogeneity, appropriately acknowledges the diversity of settings and data sources.

However, several limitations demand candid acknowledgment. First, the heterogeneity of data sources; GBD modelled estimates, national surveillance, and primary cohort studies, introduces systematic variation that meta-regression can only partially address. GBD estimates, whilst standardized, rely on modelling assumptions that may smooth over local outbreaks or underreporting; primary surveillance data are contextually grounded but often incomplete [42,62-70]. Second, publication bias is a persistent concern: studies documenting outbreaks or high burden are more likely to be published than those confirming stable or declining trends, potentially inflating pooled estimates. Third, and perhaps most consequentially, the paucity of real-time post-2023 data means that this review captures the immediate aftermath of pandemic disruption but not its full, protracted consequences. The measles spikes documented here are likely harbingers rather than endpoints; the true post-pandemic VPD landscape will only emerge as longer-term data become available. Finally, the geographic concentration of studies in Nigeria and Ethiopia, whilst epidemiologically justified, limits generalizability to under-researched regions such as Central and Southern Africa, where conflict, underfunding, and logistical barriers constrain both surveillance and research capacity.

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