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Prevalence, Distribution, and Drivers of Malaria Treatment Failure in Africa, 2000-2025: A Systematic Review and Meta-Analysis

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Abstract

Introduction:

Treatment is the cornerstone for malaria control worldwide, although malaria treatment failure remains a global threat to disease management. Several antimalarials have been used against *Plasmodium* infection; however, treatment failure has occurred over time following their use. Mapping the distribution of treatment failure and its determinants is crucial for evidence-based strategies to improve treatment efficacy.

Methods

This systematic review and meta-analysis pooled the distribution, prevalence, and key determinants of malaria treatment failure in Africa from January 2000 to December 2025, using PRISMA 2020 guidelines (PROSPERO: CRD420261340171); databases (PubMed, Web of Science, Scopus, and Google Scholar) and grey literature were searched. Rayyan was used for data extraction, with assessment using the JBI tool, and data were analyzed using Python v3.13 to determine the distribution, temporal prevalence, and drivers of malaria treatment failure.

Results

Out of 1,414 studies accessed, 159 from 27 African countries identified both malaria treatment failure and its determinants. The pooled prevalence of malaria treatment failure was 14.3%, while drivers were reported as parasite-related factors (n = 100; 62.1%), host-related factors (n = 66; 41.5%), drug-related factors (n = 62; 38.9%), and health system-related factors (n = 19; 11.9%). High heterogeneity (I^2=98.4%) and a decline in treatment failure indicate variation in drug regimens over time and differences in geographical distribution.

Conclusions

The higher distribution of treatment failure among older antimalarial drugs (quinolines and antifolates) may reflect prolonged drug exposure and persistent parasite mutations. Molecular surveillance and treatment-efficacy monitoring should be integrated into national malaria programs in African countries to improve treatment effectiveness.

BACKGROUND

Malaria is a significant global health concern, particularly in sub-Saharan regions. In 2025, an estimated 282 million cases and 610,000 deaths occurred globally, with approximately 94% of cases reported in African regions. [1]. Human malaria is caused predominantly by five *Plasmodium* species: *P. falciparum,*

P. vivax, P. ovale, P. malariae, and P. knowlesi, of which *P. falciparum* accounts for malaria-related morbidity and mortality in Africa [2]. Antimalarial drugs have been a cornerstone of malaria management and control, with artemisinin-based combination therapies (ACTs) recommended as the first-line treatment for uncomplicated malaria in *Plasmodium falciparum* endemic regions [3]. However, treatment failure continues to be reported and may compromise therapeutic effectiveness and malaria control efforts. [4].

The emergence of antimalarial drug resistance has historically threatened treatment efficacy. Widespread chloroquine resistance contributed to the loss of chloroquine efficacy in many endemic settings and prompted changes in malaria treatment policies, including the adoption of ACTs [3, 5]. ACTs combine rapidly acting artemisinin derivatives with longer-acting partner drugs and remain highly effective in most settings. Nevertheless, treatment failures continue to be reported, raising concerns about the emergence and spread of resistance as well as other factors that may compromise therapeutic outcomes. Nevertheless, despite these interventions, treatment failure to antimalarials continues to be reported globally, with increasing concerns in sub-Saharan Africa, the region that bears the highest burden of malaria transmission.

Parasite, host, drug, and health system factors have been associated with malaria treatment failure [6–8]. The emergence and selection of genetic mutations associated with antimalarial resistance represent one of the major determinants of malaria treatment failure. Mutations include the *pfcrt* gene associated with chloroquine resistance, *pfmdr1* associated with altered susceptibility to several antimalarial drugs, *pfdhfr* and *pfdhps* associated with sulfadoxine–pyrimethamine resistance, and pfkelch13 mutations linked to artemisinin partial resistance [9, 10]. Parasite factors such as high baseline parasite density, delayed parasite clearance, and parasite genetic diversity have been reported to influence treatment outcomes and contribute to recurrent infections [11]. Studies highlighted the role of host immunity in parasite clearance and clinical recovery, with individuals living in high-transmission settings often developing partial immunity that modifies disease severity and treatment outcomes. Additionally, inappropriate prescribing practices have been implicated in reduced treatment effectiveness and the selection of resistant parasite populations that emerge worldwide [12].

Despite extensive therapeutic efficacy studies across malaria-endemic African countries, evidence on treatment failure remains heterogeneous. While previous reviews focused on prevalence and risk factors of malaria parasitaemia [13, 14], a comprehensive synthesis of treatment-failure estimates across Africa, together with their geographic and temporal distribution and the factors reported in association with treatment failure, may therefore provide a broader understanding of variation in therapeutic outcomes and identify important evidence gaps.

Therefore, this systematic review and meta-analysis aimed at the synthesis of available data in the past two and a half decades on drivers of malaria treatment failure in Africa, with the ultimate goal of providing an update on the pooled prevalence and associated factors. The review aims to provide evidence to complement WHO recommendations on antimalarial treatment policies and inform future research priorities.

METHODS

Protocol Registration

This systematic review and meta-analysis is in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [15]. The review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO; CRD420261340171).

Search Strategy

A systematic literature search was conducted in PubMed, Scopus, Web of Science, and Google Scholar to identify studies reporting malaria treatment failure and associated factors in Africa. The search covered studies published between 1 January 2000 and 31 December 2025 and was supplemented by manual screening of reference lists and searches of institutional repositories for relevant grey literature. Google Scholar was searched using Publish or Perish software (version 8.19.5300.9483) [16], with screening limited to the most relevant 200 results for feasibility [17]. The complete database-specific search strategies, search dates, and numbers of records retrieved are provided in a supplementary file (S1 Table).

Eligibility Criteria

Studies were eligible if they were published in English between 2000 and 2025, conducted among human participants in Africa, and reported both malaria treatment failure and associated determinants following antimalarial treatment. Eligible study designs included observational studies (cohort and case-control) and experimental studies. Systematic reviews, meta-analyses, cross-sectional studies, conference abstracts, opinions, commentaries, other non-original publications, and studies reporting malaria treatment failure without assessing its associated determinants were excluded.

Study selection

All retrieved records were imported into Rayyan software for duplicate removal and screening.

Two reviewers (DB and EN) independently screened titles and abstracts against predefined eligibility criteria (S1 file). Full texts of potentially eligible articles were subsequently assessed for eligibility by two reviewers (OI and EN), and reasons for exclusion at the full text stage were documented (S2 file).

Data Extraction

Data were extracted using a standardized data abstraction form. The extracted data included publication year, country, study design, sample size, antimalarial regimen, follow-up duration, treatment failure outcome, prevalence of treatment failure, and reported factors associated with treatment failure. Discrepancies in data extraction were resolved through discussion with a third reviewer until consensus was reached. The completed data abstraction form is provided in a supplementary file (S3 file).

Risk of Bias Assessment

Risk of bias was assessed using the JBI Critical Appraisal Checklist for Cohort Studies [18]. The checklist evaluated potential sources of bias related to sampling frame, sampling method, sample size, participant and setting description, coverage of the identified sample, validity and reliability of condition measurement, statistical analysis, and response rate. The quality appraisal of each included study is demonstrated in the additional file (S4 file).

Data analysis

Data management and statistical analyses were performed using Python version 3.13, with pandas for data handling, and NumPy and SciPy for numerical and statistical computation, and Matplotlib for geographical presentation. Prior to analysis, extracted data were cleaned and standardized. Country names were harmonized, and antimalarial regimens were classified as artemisinin derivatives, combination/multi-class regimens, antifolates, or quinolines. Treatment outcomes were categorized according to WHO classifications as Early Treatment Failure (ETF), Late Clinical Failure (LCF), and Late Parasitological Failure (LPF), and publication periods were derived from the extracted data.

Quantitative Synthesis (Meta-Analysis) and Subgroup Analysis

PCR-adjusted malaria treatment failure prevalence was the pre-specified effect measure for quantitative synthesis. Prevalence values were pooled using a DerSimonian–Laird random-effects model fitted after Freeman–Tukey double-arcsine transformation and back transformed to percentages using harmonic-mean sample size. Between-study heterogeneity was assessed using Cochran's Q, the between-study variance (τ^2), and the I^2 statistic, and Meta-regression analysis was subsequently conducted to investigate whether predefined study-level characteristics explained the observed heterogeneity. Pre-specified subgroup analyses were conducted according to WHO treatment outcome category, antimalarial drug class, population group, publication period, study design, and country. Separate DerSimonian–Laird pooled estimates were calculated for each subgroup, and differences between subgroup estimates were assessed using z-tests on the pooled transformed estimates.

RESULTS

The database search yielded 1414 records. After screening the titles and abstracts against the eligibility criteria, 176 articles were retrieved for full-text assessment. Following full-text screening, 123 articles met the inclusion criteria and were included in the systematic review. In addition, 36 articles were

identified through grey literature sources and were included in the review, resulting in a total of 159 articles, as summarized in a PRISMA 2020 flow diagram (Fig. 1). Across all 159 studies published between 2000 and 2025 in Africa, those that met the inclusion criteria were included in the analysis.

This review covered 27 countries located in WHO endemic regions of Africa, with the majority of studies reporting malaria treatment failures found in Uganda (17.7%; k=37) and Nigeria (20.7%; k=20) (S2 table). The random-effects pooled prevalence of malaria treatment failure was 14.3% (95% CI 12.28–16.51%).

Geographic Distribution of Malaria Treatment Failure Prevalence across Africa

Country-level pooled estimates showed substantial geographic variation in malaria treatment failure across the 27 African countries represented in the review (Fig. 2). The highest pooled prevalence was observed in the Republic of Congo (33.0%), Gabon (28.9%), and Nigeria (20.7%). Followed by East and Central African countries, such as Kenya (18.0%), Uganda (17.7%), the Democratic Republic of the Congo (16.4%), and Cameroon (15.5%), whereas lower estimates were observed in Guinea (1.0%), Senegal (1.2%), Benin (2.0%), Rwanda (4.5%), Angola (6.1%), and Ethiopia (6.8%). Countries with no eligible studies are shown in grey and were not included in the pooled analysis. (S 2 Table and S 1 Fig). Countries shown in grey had no eligible records in this review and are not part of the pooled analysis.

Subgroup Analysis of Malaria Treatment Failure

Across six key study-level variables, pooled prevalence of malaria treatment failure was high in the three components of the WHO treatment-outcome classification, with Early Treatment Failure (17.2%; 95% CI 13.8–21.0%; k=69), Late Clinical Failure (17.8%; 95% CI 14.1–21.7%; k=75), and Late Parasitological Failure (13.2%; 95% CI 11.1–15.5%; k=133), All three subgroup estimates carried very high heterogeneity (I^2>98%). However, the results were corrected for reinfection by genotyping, which disproportionately reclassifies late recurrences as new infections rather than true treatment failure (recrudescence); therefore, the adjusted overall pooled estimate of treatment failure was 14.3%. While the majority of studies reporting malaria treatment failure prevalence involved patients with uncomplicated malaria (14.3%; k =153), studies involving patients with complicated malaria reported a higher prevalence of treatment failure (16.7%; k =2), whereas the lowest prevalence was observed among asymptomatic malaria cases (12.4%; k =2). Prevalence of treatment failure differed markedly by antimalarial drug class, with artemisinin derivatives (10.3%; 95% CI 6.4–15.0%; k=42) and combination multi-class regimens (10.6%; 95% CI 8.4–13.1%; k=65) showing the lowest pooled prevalence, roughly half that observed for antifolates (20.8%; 95% CI 15.7–26.4%; k=25) and less than half that of quinolines (26.7%; 95% CI 18.8–35.4%; k=27), the highest-prevalence class (Table 2).

Classification by specific drug, all non-artemisinin regimens showed the highest mean prevalence with chloroquine plus sulfadoxine-pyrimethamine (35.1%), sulfadoxine-pyrimethamine alone (24.8%), chloroquine alone (22.6%), and quinine (21.3%), and the lowest-prevalence regimens were among artemisinin-based therapy: artesunate-mefloquine (2.1%), artesunate monotherapy (4.1%), artesunate-amodiaquine (4.9%), and pyronaridine-artesunate (6.4%) (Fig. 4). When stratified by population group,

children were heavily represented in the group (14.9%), pregnant women (15.7%), HIV-infected patients (18.2%), adults (14.4%), and mixed/other populations (11.2%), all of which produced overlapping confidence intervals that crossed the overall pooled prevalence of 14.3%. Additionally, the review identified four major categories of drivers of malaria treatment failure among the included studies: parasite, host, drug, and health system-related factors. Parasite-related factors were the most frequently reported (k=100; 62.1%), followed by host-related factors (k=66%; 41.5%), drug-related factors (k=62; 38.9%), and health system-related factors (k=19; 11.9%), respectively (Table 2).

Table 1. Pooled prevalence of malaria treatment failure by key study-level variables.

Variable/Subcategory	k (Records)	Pooled Prevalence (%)	95% CI	Tau²	I² (%)	Cochran's Q (df)	p-value
WHO Treatment Outcome Category							
ETF	69	17.2	13.8–21.0	0.0399	98.7	5127.24 (68)	<0.001
LCF	75	17.8	14.1–21.7	0.0458	98.7	5725.82 (74)	<0.001
LPF	133	13.2	11.1–15.5	0.0348	98.3	7553.26 (132)	<0.001
Antimalarial Drug Class							
Artemisinin derivatives	42	10.3	6.4–15.0	0.0526	98.8	3459.94 (41)	<0.001
Combination (multi-class)	65	10.6	8.4–13.1	0.0232	97.8	2847.47 (64)	<0.001
Antifolates	25	20.8	15.7–26.4	0.0272	98.0	1197.35 (24)	<0.001
Quinolines	27	26.7	18.8–35.4	0.0593	98.4	1625.66 (26)	<0.001
Publication Period							
2000–2009	79	20.3	17.0–23.8	0.0343	98.2	4436.76 (78)	<0.001
2010–2017	48	9.3	6.2–12.9	0.0393	98.7	3490.61 (47)	<0.001
2018–2025	32	9.3	6.3–12.9	0.0250	97.2	1108.59 (31)	<0.001
Population Group							
Children	114	14.9	12.4–17.5	0.0375	98.5	7515.68 (113)	<0.001
Pregnant women	8	15.7	5.2–30.4	0.0630	99.0	712.80 (7)	<0.001
HIV-infected patients	6	18.2	11.5–26.1	0.0114	88.8	44.50 (5)	<0.001
Adults	4	14.4	11.6–17.4	0.0012	74.9	11.97 (3)	0.007
Mixed/Other	27	11.2	7.1–16.1	0.0343	97.9	1213.75 (26)	<0.001

Variable/Subcategory	k (Records)	Pooled Prevalence (%)	95% CI	Tau²	I² (%)	Cochran's Q (df)	p-value
Malaria Clinical Status							
Uncomplicated malaria	153	14.3	12.2–16.5	0.0363	98.3	9111.43 (152)	<0.001
Severe Malaria	2	16.7	6.8–29.9	0.0115	90.2	10.19 (1)	0.001
Asymptomatic malaria	2	12.4	7.5–18.3	0.0030	85.5	6.90 (1)	0.009
Determinants (Domain)							
Parasite factors	100	15.3	12.8–18.0	0.0321	98.1	5122.10 (99)	<0.001
Host factors	66	14.2	11.0–17.8	0.0398	98.7	5161.34 (65)	<0.001
Drug factors	62	11.5	9.1–14.2	0.0247	97.7	2597.33 (61)	<0.001
Health system factors	19	16.0	10.4–22.5	0.0325	98.4	1127.98 (18)	<0.001

Temporal Trends of Malaria Treatment Failure in Africa

The findings showed a highly significant declining trend with a slope of −0.0111 per year, SE=0.0024, z=−4.70, p<0.0001 (Fig. 6 and Table 3), corresponding to an approximate decline of 0.78 percentage points per year of publication in absolute prevalence terms near the mean. Mean prevalence of malaria treatment failure declined significantly over the study period, from 2001 to single-digit or low-double-digit values for most years after 2010. A sample-size-weighted linear trend across all 25 years indicates a decline of approximately 0.95 percentage points per year (Fig. 3). This mirrors the publication-period sub-category comparison reported in Table 1, in which pooled prevalence fell from 20.3% (2000–2009) to 9.3% (2010–2017) and remained statistically unchanged thereafter (9.3%, 2018–2025). Individual years with very few records (e.g., 2022, k=1; 2024, k=2) show correspondingly wide error bars and should not be over-interpreted as representing a genuine year-on-year reversal of the broader downward trend.

Temporal Trends in Antimalarial Drugs Studied

The decline in prevalence of treatment failure coincides with a clear shift in which drug regimens were being studied. Sulfadoxine-pyrimethamine and other older regimens (grouped as “other regimens”) dominate the literature prior to 2005, whereas artemether-lumefantrine, artesunate-amodiaquine, and dihydroartemisinin-piperaquine become the predominant regimens studied from the mid-2000s onward,

particularly in the high-output years 2011, 2017, and 2020 (Fig. 4). This transition in the evidence base itself, rather than a change in the efficacy of any single regimen over time, plausibly accounts for a substantial part of the temporal decline in pooled prevalence, since the literature progressively shifted from studying higher-failure older regimens to lower-failure artemisinin-based combination therapies.

Temporal trends in drivers (parasites, host, drug, facility) of treatment failure

Reporting of parasite factors, mainly molecular resistance markers, as a driver of treatment failure rose sharply from the early 2000s, peaking in 2005–2009 with up to ten records per year, a period that coincides with the intensified genotyping and resistance-surveillance activity accompanying the continent-wide rollout of artemisinin-based combination therapy. Host and drug factors were reported at broadly comparable, lower frequencies throughout the period, while health-system factors were the least frequently reported domain in every year (k=19). Reporting of all domains has been markedly lower and more sporadic since 2012 than during the 2005–2009 peak, which may reflect a shift in research focus once first-line ACT policies had been established across most of the region studied. The parasite-related factors were reported consistently across the study period, with evidence appearing in almost every year between 2000 and 2025 (Fig. 5).

The persistent temporal pattern highlights the continuing contribution of parasite-related mechanisms, particularly genetic mutations associated with reduced antimalarial susceptibility and treatment failure. The repeated identification of these factors over time suggests that the emergence and spread of resistance-associated mutations remain an ongoing concern.

Publication Bias Assessment

Publication bias: visual inspection of the funnel plot shows a broad and somewhat asymmetric scatter of records around the pooled effect, with several small, high-prevalence studies (large standard error) situated to the right of the pooled estimate. Formal testing produced discordant results: Egger's regression test did not indicate significant funnel asymmetry (intercept=0.535, SE=1.499, t(157)=0.36, p=0.722), whereas Begg's rank correlation test was significant (Kendall's τ=0.178, p=0.0009). This discordance should be interpreted cautiously: Egger's regression test is known to lose reliability when between-study heterogeneity is very high (I^2>90%), as is the case here (I^2=98.4%), and the extreme diversity of drug regimens, countries, and follow-up schedules pooled in this analysis provides a more parsimonious explanation for funnel asymmetry than publication bias per se (Fig. 6).

DISCUSSION

This systematic review and meta-analysis aimed to synthesize prevalence and drivers of malaria treatment failure, and evidence of malaria treatment failure among 159 studies across 27 countries of Africa was analyzed. Drivers were classified into host, parasite, drug, and health-system factors reported as key determinants of malaria treatment failure (Table 1). In the pooled prevalence of treatment failure, parasite-related factors were mainly observed (62.1%) in all records. These findings underscore that the

emergence and spread of parasite genetic mutations associated with antimalarial resistance remain a major global health concern. Their increasing detection highlights the capacity of *Plasmodium* parasites to adapt to drug pressure, potentially reducing treatment efficacy.

The geographic distribution of treatment failure varied substantially across WHO malaria endemic regions of Africa; treatment failure was most frequently reported in studies conducted in Uganda (k = 37) and Nigeria (k = 20), with a prevalence of failure of 17.7% and 20.7%, respectively. Similarly, a slightly higher prevalence of treatment failure was observed in Central Africa, particularly the Republic of Congo and Gabon, with prevalence ranging from 15 to 21%. These findings are consistent with WHO reports, which highlighted the role of parasite genetic mutations, *pf*crt and *pf*k13 polymorphisms, as well as transmission intensity and drug exposure, in treatment failure [19]. This indicates that declining drug efficacy may continue despite the current combination of other drugs with artemisinin.

The highest prevalence of treatment failure was observed in patients treated with quinolines (26.7%) and antifolates (20.8%), whereas artemisinin derivatives (10.3%) and multi-class combination regimens (10.6%) showed considerably lower prevalence. These findings may be explained by the prolonged use of quinolines and antifolates [3], which has exerted sustained drug pressure and contributed to the selection and emergence of resistant *Plasmodium* parasites [20]. In contrast, ACTs adopted in the early 2000s remain more effective and the recommended first-line treatment for uncomplicated malaria according to WHO guidelines [21]. However, the increasing reports of treatment failure with ACTs highlight the evolving threat of antimalarial resistance and underscore the need for continuous therapeutic efficacy monitoring and molecular surveillance [22, 23]. The temporal analysis showed an apparent decline in treatment failure from 2000 to 2025. This decline coincided with a major change in the antimalarial regimens investigated over time. The findings show that older drugs dominated the literature before 2005, while recently used drugs, ACTs including artemether-lumefantrine (AL), artesunate-amodiaquine (ASAQ), and dihydroartemisinin-piperaquine (DHA-PPQ), became increasingly investigated after the mid-2000s.

According to Igwe et al. [24], the use of antimalarial drugs imposes selective pressure on *Plasmodium* populations, favoring the emergence, selection, and spread of drug-resistant strains through parasite genetic adaptation, thereby undermining the effectiveness of antimalarial treatment. Similarly, parasite factors were the most frequently reported in treatment failure. In addition, the high heterogeneity (I^2 > 98%) demonstrates substantial variability in treatment outcomes across studies (S 3 Table). This reinforces the importance of considering interactions between parasite, host, and drug-related factors, as their interactions may influence antimalarial drug efficacy and ultimately determine treatment outcomes [25, 26].

Treatment failure was more frequently reported among children (n = 114; 71.7%), suggesting a potentially greater vulnerability in this population, possibly due to high vomiting after medication and low immunity of this group [11]. This review showed that treatment failures occurred across clinically diverse populations, with people living with HIV recording the highest point of 18.2%. However, this should not be

solely interpreted as evidence of a direct effect of the HIV infection because the present studies vary in the clinical characteristics, treatment regimens, and study design.

In this review, some years reported very few studies, which should not be interpreted as reliable evidence of year-to-year changes (e.g., 2022, k = 1; 2024, k = 2). Future research should focus on therapeutic efficacy monitoring and identifying contributing factors to better anticipate, prevent, and mitigate malaria treatment failure. The observed imbalance may result from the fact that research has concentrated heavily on the biological mechanisms rather than on the potentially modifiable factors operating within malaria case management. Enhancing therapeutic efficacy surveillance should be supported by reliable diagnosis, appropriate prescribing and dosing, adherence support, and functional pharmaceutical supply systems. Additionally, WHO insists on continuous monitoring of antimalarial efficacy and resistance to maintain treatment policies aligned with the prevailing epidemiological and resistance landscape [27].

Limitations

The included studies in this review were follow-up and experimental, for linking drivers with treatment outcomes; thus, cross-sectional studies were not considered due to limitations in providing evidence on treatment outcomes. In addition, studies that reported treatment failure without assessing causal relationships were excluded, which may have reduced the number of eligible studies and potentially limited the available evidence on treatment failure. Few studies relied solely on microscopy to assess treatment failure without incorporating genotyping approaches to distinguish recrudescence from reinfection, potentially leading to an overestimation of treatment failure prevalence observed in some studies.

CONCLUSION

This systematic review demonstrated the distribution of malaria treatment failure across Africa over two and a half decades, while identifying factors contributing to treatment failure across the included studies. Parasite-related factors emerged as the most prominent contributors to treatment failure, while host, clinical, pharmacological, immunological, and treatment-related factors also play important roles. Older quinolines and antifolates had higher failure rates than artemisinin derivatives and combination regimens, emphasizing the need to protect the effectiveness of the current antimalarial treatments. African countries should bolster therapeutic efficacy surveillance, rational prescribing, adherence, and access to quality-assured medicines. Future research should extend beyond molecular surveillance to investigate other confounding and contributing factors such as host immunity and drug-related factors that may reduce treatment efficacy and use longitudinal follow-up approaches to better elucidate the mechanisms and temporal trends underlying malaria treatment failure. Further research into novel malaria vaccines should be prioritized, as should improving surveillance and monitoring of antimalarial therapy to maintain treatment efficacy.

Abbreviations

WHO: World Health Organization

ACT: Artemisinin-based Combination Therapy

PCR: Polymerase Chain Reaction

ETF: Early Treatment Failure

LCF: Late Clinical Failure

LPF: Late Parasitological Failure

Declarations

Author contributions

Conceptualization: O.I., E.A., L.M., and D.S.; Data extraction: O.I. and H.F.; Data analysis: R.N and O.I.; Writing and original draft: T.A.T., E.L.N., and OI; Review and editing: C.M., E.S., and T.A.T. Validation: E.A. and D.S. Funding acquisition: L.M. All authors have read and approved the final published version of the manuscript.

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Data and materials availability

The data used in this review are available from the corresponding author, and the supplementary files are submitted with the manuscript.

Ethics and consent to participate

All data included in this analysis were derived from studies conducted in accordance with the applicable national laws, ethical standards, and institutional approvals of the respective countries. The original studies obtained informed consent from the participants, where applicable. As this review involved secondary analysis of previously published data and did not involve direct contact with human participants or access to identifiable personal information, ethical review was not required under the guidelines of the University of Rwanda Research Ethics Committee.

Consent for publication

Not applicable

Conflict of interest

The authors declare that this review was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Figures

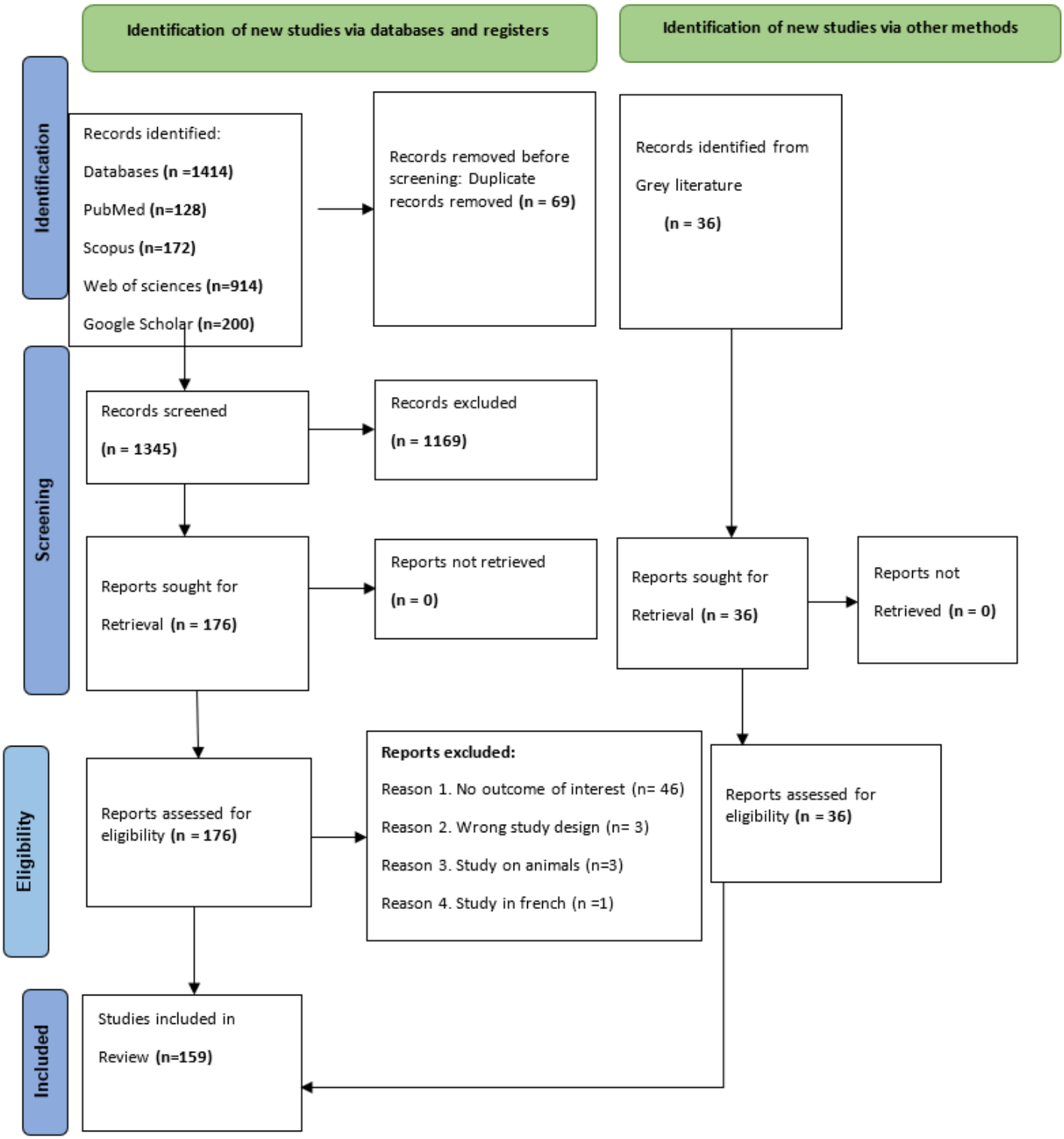
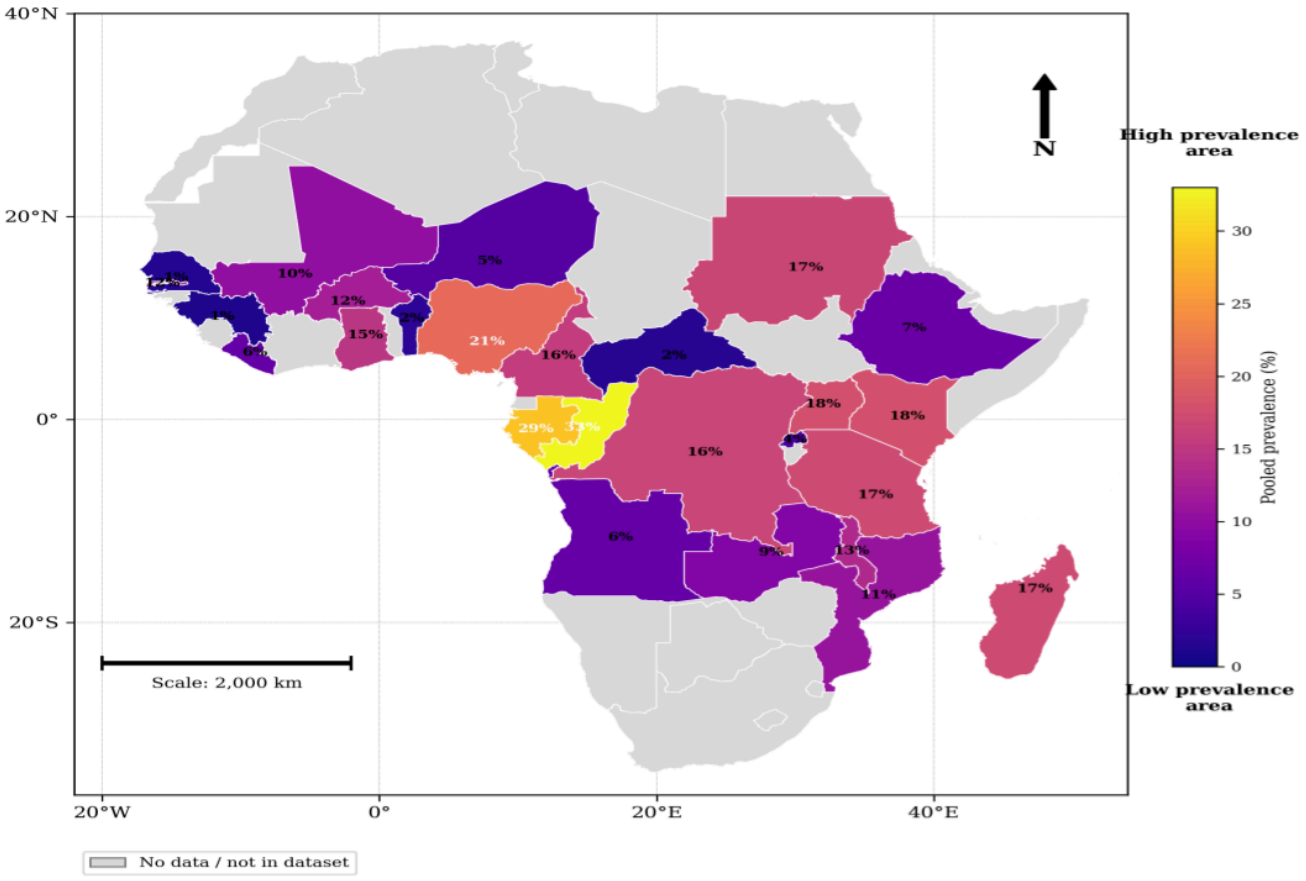


Figure 1

PRISMA flow chart of the systematic review



Source: Extracted systematic review records (2000–2025). Values = DerSimonian–Laird random-effects pooled prevalence per country. Projection: Plate Carrée (equirectangular).

Figure 2

Geographical distribution of pooled malaria treatment failure prevalence across African countries. The Colour scale runs from low (dark purple) to high (yellow) pooled prevalence; grey indicates countries with no eligible records.

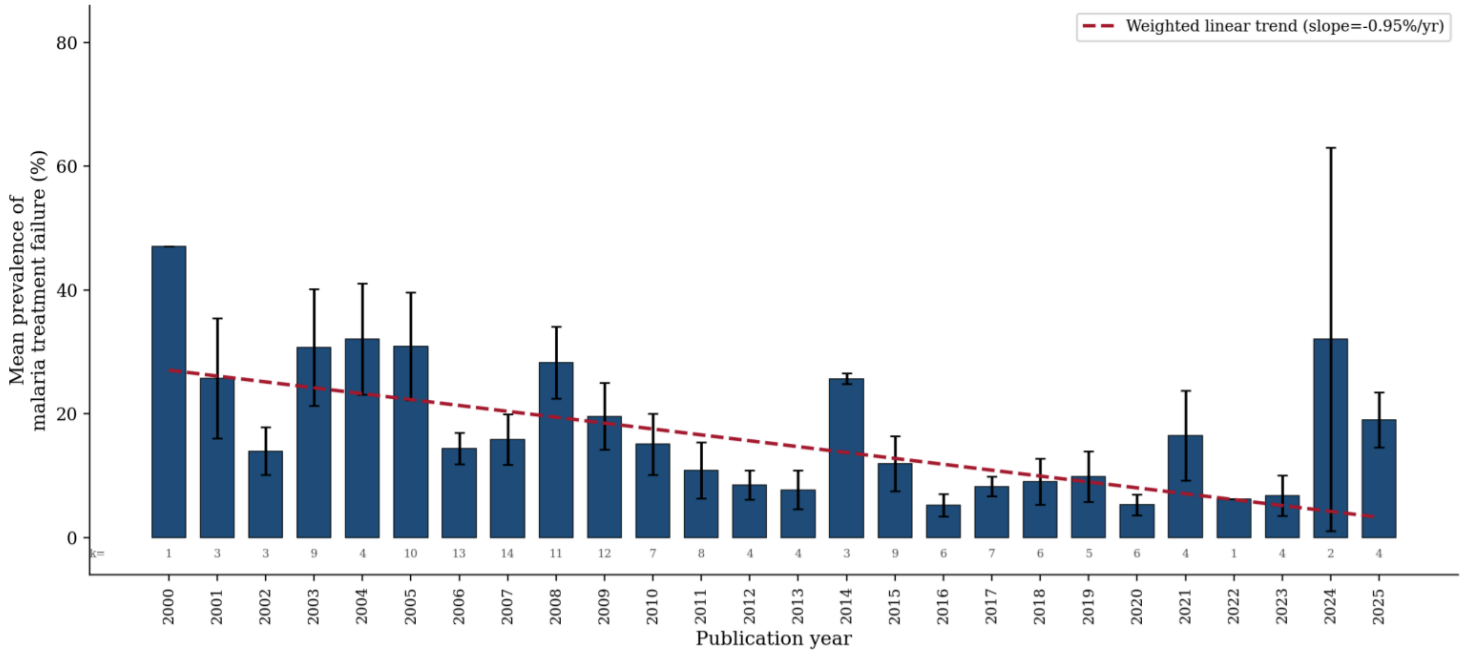


Figure 3

Trend in malaria treatment failure prevalence by publication year, 2000–2025, with a sample-size-weighted linear trend line. Error bars show ± 1 standard error; k values below the x-axis show the number of records contributing to each year.

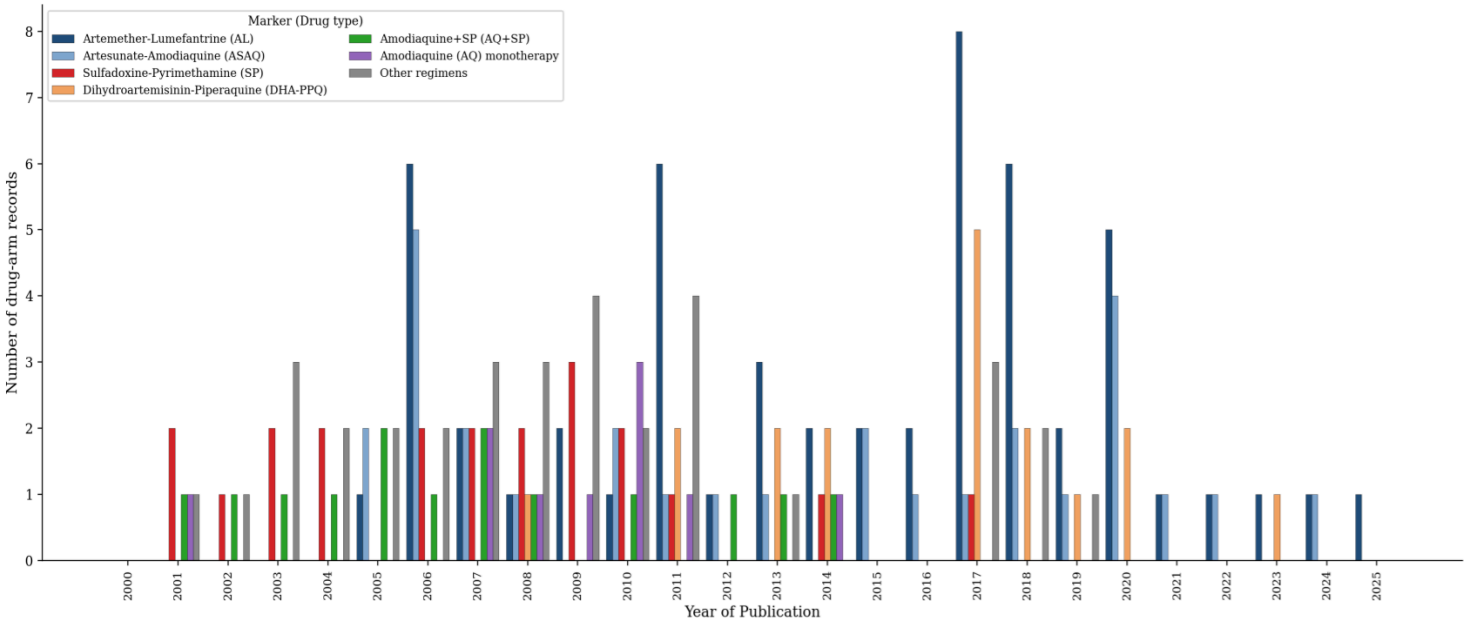


Figure 4

Number of drug-arm records by antimalarial drug type and publication year, 2000–2025 (top six most-studied regimens shown individually; remaining regimens grouped as “other”).

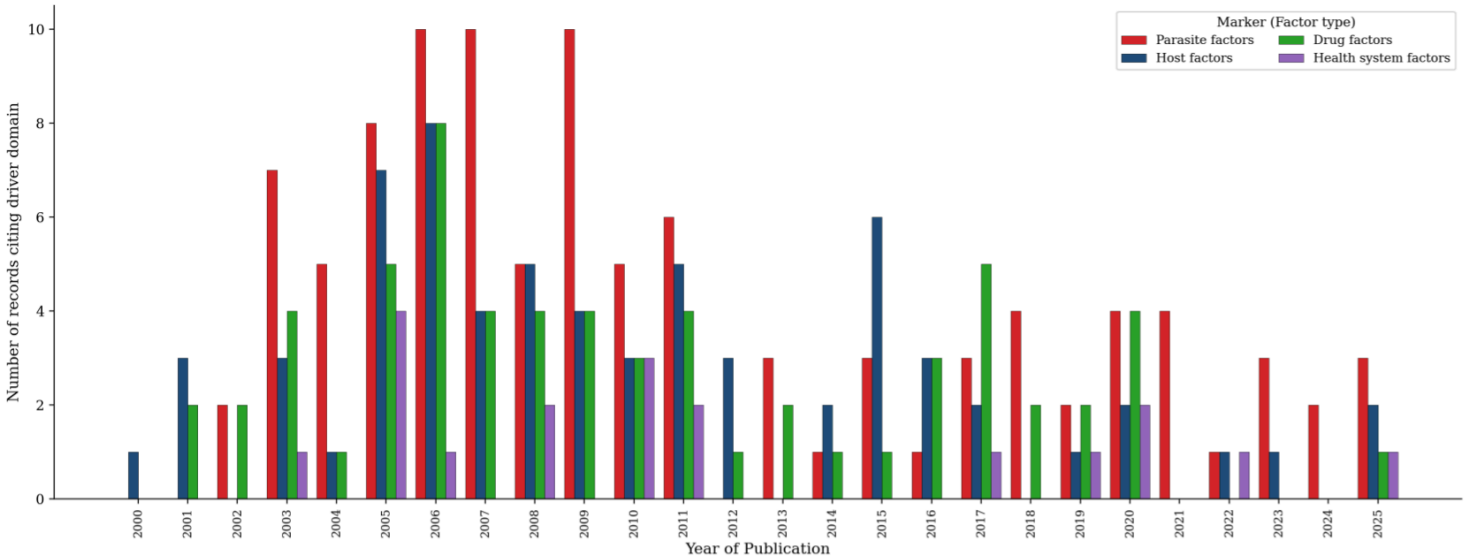


Figure 5

Number of records citing each driver domain (host, parasite, drug, health-system factors) by publication year, 2000–2025.

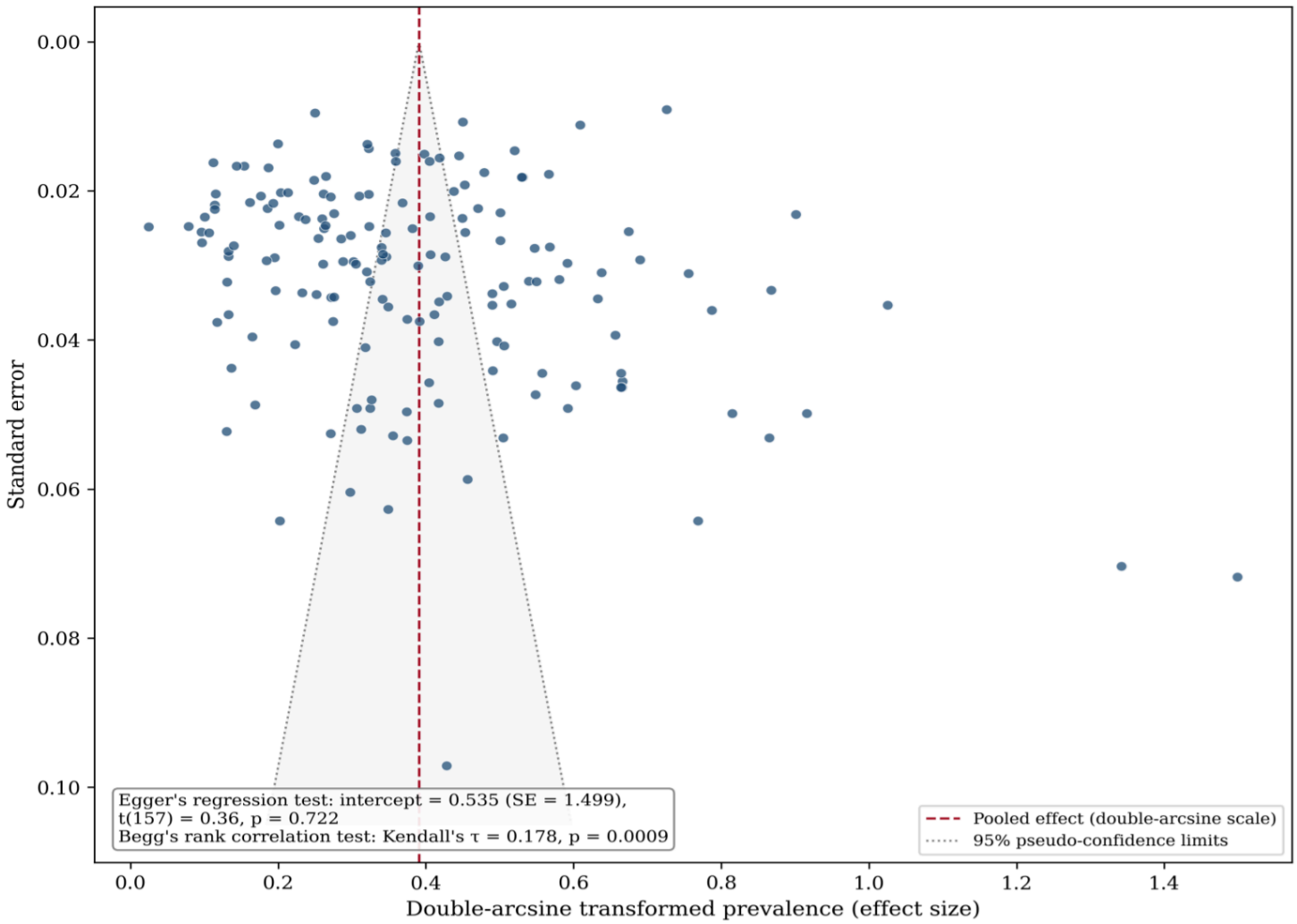


Figure 6

Funnel plot of the prevalence of malaria treatment failure against its standard error (k=159 records).

Supplementary Files

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- Supplementarytablesandfigures.zip