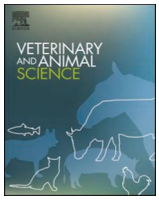
Veterinary and Animal Science 26 (2024) 100410

Contents lists available at ScienceDirect

Veterinary and Animal Science

journal homepage: www.elsevier.com/locate/vas



A systematic review and meta-analysis of contagious bovine pleuropneumonia in Ethiopian cattle

Melkie Dagnaw Fenta [a,*], Marshet Bazezew [b], Wassie Molla [b], Mebrie Zemene Kinde [c,*], Bemrew Admassu Mengistu [c], Haileyesus Dejene [b]

[a] Department of Veterinary Clinical Medicine, College of Veterinary Medicine and Animal Sciences, University of Gondar, Ethiopia
[b] Department of Veterinary Epidemiology and Public Health, College of Veterinary Medicine and Animal Sciences, University of Gondar, Ethiopia
[c] Department of Veterinary Biomedical Sciences, College of Veterinary Medicine and Animal Sciences, University of Gondar, Ethiopia

ARTICLE INFO

Keywords:
Contagious bovine pleuropneumonia
Ethiopia
Sero prevalence
Systematic review
Meta-analysis

ABSTRACT

Contagious bovine pleuropneumonia (CBPP) is a severe respiratory disease in cattle, caused by Mycoplasma mycoides subsp. mycoides. It poses a major threat to cattle health and livestock productivity. We aimed to pool CBPP prevalence estimates from different regions of Ethiopia, assessing implications for cattle management and productivity. The review followed PRISMA guidelines and searched PubMed, Web of Science, Scopus, HINARI, Google, and Google Scholar from January to February 2024. Funnel plots and Egger's regression tests were used to assess publication bias and small study effects. A pooled prevalence and 95 % confidence interval (CI) were calculated using R software. Twenty-three studies, covering 52,373 cattle, showed high heterogeneity ($I^2 = 99$ %, $p < 0.0001$). The pooled CBPP prevalence in Ethiopia was 13 % (95 % CI: 7–21 %). Geographic differences, sampling methods, and cattle management practices influenced prevalence rates. There was no indication of publication bias (Egger's test, $p = 0.618$). Prevalence was highest in the eastern (18 %), western (15 %), northern (14 %), and southern (4 %) regions. The prevalence was 16 % post-2016, compared to 8 % before 2016. Meta-regression showed that study location, herd size, body condition, and publication year significantly impacted CBPP prevalence. Small herds had 59 % lower CBPP risk, and animals in poor condition had 2.34 times higher odds of CBPP. The findings suggest a changing prevalence trend and emphasize the need to update CBPP prevention and control policies.

1. Introduction

Contagious bovine pleuropneumonia is a transboundary and contagious respiratory bacterial disease of cattle caused by *Mycoplasma mycoides* subsp. *Mycoides* (*MmmSC*), which belongs to the *Mycoplasma mycoides* cluster (Radostits & Done, 2007). "Contagious bovine pleuropneumonia (CBPP) is a severe OIE-notifable respiratory disease of cattle characterized by intense fibrous bronchopneumonia and pleural effusion. Because of its high mortality and morbidity rates, CBPP can result in significant productivity losses for the livestock industry in general and for cattle in particular (Thiaucourt *et al.*, 2021).

The transmission of *MmmSCs* from animals to animals occurs mostly via respiratory aerosols. However, aerosols can transfer agents over greater distances (up to 200 m) in the presence of favourable atmospheric conditions such as humidity and wind. The bacterium is found in saliva, urine, fetal membranes, and uterine secretions (Abdela & Yune, 2017). Carrier animals, such as infected cattle, can retain viable organisms in encapsulated lung lesions (*sequestra*) for months or even years. Despite a few rare instances of transmission via fomites, mycoplasmas do not survive in the environment for more than a few days, and indirect transmission is assumed to be negligible in the epidemiology of this disease (HA, 2013; E. Garde et al., 2005). CBPP is most likely to be introduced via an infected animal (J. Jores et al., 2020).

Moreover, various factors, such as age, herd size, season, interaction with diseased animals, overcrowding in the cow population, feed and water sources, and altitude, are known to influence the occurrence of CBPP. Among these factors, altitude and herd size are the most important risk factors. In addition, CBPP seroprevalence is connected to agroecology, and there are considerable differences between agroecology. Compared with highland and mid-highland agro-ecological animals,

* Corresponding authors.
E-mail addresses: Melkie.Dagnaw@uog.edu.et (M.D. Fenta), honeyshetbazezew@gmail.com (M. Bazezew), wassiemolla@gmail.com (W. Molla), mebrie.zemene@uog.edu.et (M.Z. Kinde), vet27admasu@gamil.com (B.A. Mengistu), haileyesus.dejene@uog.edu.et (H. Dejene).

https://doi.org/10.1016/j.vas.2024.100410

Available online 14 November 2024

lowland agro-ecological animals are significantly more prevalent (Y. Mamo, 2016). CBPP occurs at a considerably higher rate during the wet season of the year (W. Kebede et al., 2022). In Ethiopia, CBPP is one of the most common contagious diseases affecting cattle. CBPP was introduced into East Africa from India by Field Marshal Napier's army during his invasion of Ethiopia in 1867–1868 (W. Masiga et al., 1996). East African countries accounted for 66 % of all outbreaks (58 % in Ethiopia and Tanzania and 8 % in other countries in the region) (Tambi *et al.*, 2006). Ethiopia is one of the East African countries where CBPP is endemically maintained throughout the country, with a morbidity rate of 25 % and a mortality rate of more than 10 % (Teklue et al., 2015; Y. Mamo et al., 2018). Studies undertaken thus far in the country have shown that the seroprevalence of CBPP ranges from 0.4 % to 96 % (E. Dele et al., 2014; Alemayehu et al., 2015b).

Furthermore, because of its high mortality rate, production loss, increased production costs due to disease control costs, loss of weight and working ability, delayed marketing, reduced fertility, loss due to quarantine, loss of cattle trade, and reduced investment in livestock production, this respiratory disease is considered of great economic importance to cattle keepers (Hurrissa & Eshetu, 2002; Radostits *et al.*, 2006). According to recent seroprevalence surveys in various regions of the country, CBPP causes large economic losses due to its associated illness and mortality. This disease also restricts international trade in animals and animal products; as a result, Ethiopia loses $8.96 million per year (G. Laval, 1999). Although the majority of the studies have either a narrow geographic scope or are largely restricted to a single agroecology, the evidence presented here strongly suggests that CBPP might be a widespread issue in Ethiopia. To demonstrate the disease's burden at the national level during the given time frame, it is crucial to compile the findings of much research that is fragmented by space and time. Additionally, a thorough awareness of the disease's prevalence and the associated risk factors in cattle across the nation should be established, as this awareness will help in the development of potential future intervention programs. Thus, this systematic review and meta-analysis aimed to estimate the national-level pooled prevalence of CBPP in Ethiopia. The specific questions of the study were as follows:

What is the pooled prevalence of CBPP in Ethiopia?

What area of the country has the highest proportion of CBPP in cattle?

What is the present prevalence rate of CBPP in comparison to the previous decade?

2. Methods

This review was carried out following the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) checklist (D. Moher et al., 2010) (Supplementary File 1). The PRISMA checklist was used to ensure that all eligible studies were incorporated into the meta-analysis. The primary goal of this review was to ascertain the overall prevalence of CBPP in Ethiopia.

2.1. Description of the study settings

The meta-analysis was carried out in Ethiopia, a nation located in the Horn of Africa, which is situated between 3° 00′–150 00′ N latitude and 320 30′–480 00′ E longitude. It encompasses a total land area of 1.04 million square kilometers. Boasting a population of 123 million individuals, Ethiopia ranks as the second most populous country in Africa after Nigeria. Ethiopia proves to be an appropriate setting for agricultural production, serving as a habitat for approximately 70, 52.5, and 42.9 million cattle, sheep, and goats, respectively (CSA, 2020). The nation has a diverse topography, which serves as the foundation for numerous agroclimatic zones. The region is situated 2300 m above sea level (m.a.s.l.) is considered highland and is encompassed by a temperate transition zone spanning 1500–2300 m.a.s.l. Areas with elevations below 1500 m.a.s.l. are classified as lowlands.

2.2. Literature search strategy

The literature search was carried out between January 2024, and February 2024. A thorough search technique was developed to examine all relevant studies. The literature search was carried out independently by two researchers (MD and WM). The online databases PubMed, Google, Google Scholar, Scopus, Web of Sciences and HINARI were explored with English language restrictions. This systematic review used the CoCoPop framework (conditions, context, and population) to search for relevant articles. The condition was CBPP (contagious bovine pleuropneumonia) (Co), the context was Ethiopia (Co), and the population was bovine (Pop). The PubMed search strategy included terms from Medical Subject Heading (MeSH) and a set of key keywords. Epidemiologically, CBPP is a contagious bacterial transboundary disease affecting large and small ruminants. The research question was as follows: What is the prevalence of CBPP in cattle in Ethiopia? The PubMed search engines used were Prevalence OR Epidemiology OR Seroprevalence OR Cross-Sectional Studies AND CBPP OR Respiratory infection OR Mycoplasma Mycoides AND Cattle OR Bovine AND Ethiopia (**Supplementary File** 2). EndNote X9 was used for removing duplicate articles.

2.3. Inclusion and exclusion criteria

The inclusion criteria were used to confirm the eligibility of the searched papers. Inclusion and exclusion criteria were defined regarding the relevance of the articles to the research questions of interest. Research articles conducted in Ethiopia; cross-sectional studies that reported the seroprevalence of CBPP; full-text articles; targeted study populations included in any management system (intensive or extensive); studies conducted via C-ELISA serological diagnostic tests; and studies indicating the total sample size and the outcome of interest. Furthermore, the sources of the selected articles were manually filtered to find relevant papers that were not found via database management system search. Case reports, articles reported only in abstracts, conferences, qualitative studies, case series, traditional reviews, and experimental (clinical studies) studies were excluded.

2.4. Quality assessment

Two independent authors (MB and HD) assessed the quality of the included papers (risk of bias) via the Appraisal tool for cross-sectional studies (AXIS tool)(M.J. Downes et al., 2016) (Supplementary File 3). This checklist contains 20 components that constitute the title, abstract, introduction, methods, results, and discussion portions of the article. The objectives, various components of the methodology (e.g., study design, sample size, study population, bias, and statistical methods), findings, limits, and funding of the investigations are all covered by the checklist.

2.5. Data extraction

After the studies that met the previous eligibility criteria were selected, the relevant data were extracted independently by two investigators (MZ and BM). In cases where they could not reach consensus, a third investigator was consulted to make the final decisions. A data collection format was prepared to extract important information from the selected articles. The data included were the first author's last name, study and publication year, study area, sample size, positive sample, risk factors, confidence interval (upper and lower), prevalence and study design.

2.6. Data synthesis and statistical analysis

The extracted data were entered and saved in a Microsoft Excel spreadsheet before being imported into R software version 4.1.3 for

analysis. To measure study heterogeneity, the inverse variance index (I^2) was calculated. Low, medium, and high heterogeneity were defined as I2 values of 25, 50, and 75 %, respectively (J.P. Higgins & Thompson, 2002). The random-effects model with the DerSimonian–Laird technique of selection (DerSimonian & Kacker, 2007) was used to calculate the pooled prevalence and 95 % confidence intervals (95 % CIs). For all included studies with the pooled effect size, a forest plot diagram was used to show the differences between studies, meta-analysis results, and their corresponding CIs.

The presence of publication bias was evaluated via a funnel plot according to M. Borenstein (2005). Cochran's Q statistic and the inverse variance index (I^2) were employed to determine the heterogeneity and inconsistency (real variation) among studies. Random effects meta-analyses were performed using the total sample size and number of positives due to the predicted variation between studies (effect size and standard error of the effect size). Furthermore, meta-regression, regression plots and subgroup analysis were used to investigate factors potentially contributing to between-study heterogeneity.

2.6.1. Subgroup analysis

Subgroup analysis is a specific type of meta-regression focused on examining the effects of a single categorical subgroup variable (J.P. Higgins & Thompson, 2002) within and across studies. In this approach, the entire set of research is divided into two or more subgroups on the basis of the categories of the subgroup variable, often termed the moderator. A moderator represents a particular characteristic of the study that can help explain some of the variation observed among the studies (Hamza et al., 2015). In this meta-analysis, the moderators include study location (eastern, western, southern, and northern), study year (pre- and post-2016), animal age (young and adult), sex (male and female), breed (local and cross), herd size (large and small), and body condition status (poor and good). To assess variability within and between sources, Cochran's Q statistic and the inverse variance index (I^2) were used. A statistically significant Q statistic for a predictor in subgroup analysis indicates that subgroup membership accounts for some or all of the variability observed in the effect sizes.

2.6.2. Meta-regression

In meta-regression, evaluating moderators follows a similar approach to regression or multiple regressions used in individual studies (Card, 2019). This method analyses the relationship between covariates (or moderators) and effect sizes across multiple studies, using the studies themselves as the units of analysis (Littell et al., 2008). It accommodates both categorical and continuous moderating variables. Researchers can incorporate a single continuous variable, such as sample size or publication year, or use a mix of several continuous variables along with categorical variables. Categorical moderators must be encoded as dummy variables in the meta-regression model. When categorical moderators are used in a meta-regression model, they must be represented as dummy variables. In this coding system, the subset of studies marked as 0 serves as the reference group, which is represented by the intercept in the fitted mixed-effects regression model. The subset marked as 1 is then compared to this reference group (e.g., "male" may be used as the reference group for sex). Meta-regression and meta-regression plots were used in this investigation. The meta-regression model can be expressed by the following equation:

$$\mathbf{ES_1}(\mathbf{prevalenceofCBPP}) = \beta_0 + \beta_1 X_I + \delta_i + e$$
$$\mathbf{ES_{Age}}(\text{prevalenceofCBPP}) = \beta_0 + \beta_1(\text{young}) + \delta_i + \text{e}_{\text{i}\ldots\ldots\ldots}(\text{Youngreference})$$
$$\mathbf{ES_{Age}}(\text{prevalenceofCBPP}) = \beta_0 + \beta_1(\text{young}) + \delta_i + \text{e}_{\text{i}\ldots\ldots\ldots}(\text{Youngreference})$$
$$\mathbf{ES_{herdsize}}(\text{prevalenceofCBPP}) = \beta_0 + \beta_1(\text{small}) + \delta_i + \text{e}_{\text{i}\ldots\ldots\ldots}(\text{Largeherdsizereference})$$
$$\mathbf{ES_{BCS}}(\text{prevalenceofCBPP}) = \beta_0 + \beta_1(\text{poor}) + \delta_i + \text{e}_{\text{i}\ldots}(\text{Goodbodyconditionsreference})$$

X_i represents a continuous or categorical moderator, and β_1 is the regression slope. δ_i and e_i are the between- and within-study error terms for study i, respectively. β_0 is the model intercept, but it now represents the overall true effect size when $X = 0$. ES_i represents the observed effect size (the prevalence of the CBPP) for study i, which is an estimator of the study's true effect size. By accounting for both sampling error and variations between studies, meta-regression aims to fit a model that is generalized across all relevant studies. A well-fitted meta-regression model should predict effect sizes that closely match the observed data. By using the R^2 statistic, meta-regression analysis can quantify how much variability can be explained by moderators across various studies (i.e., heterogeneity).

3. Results

3.1. Search result

This systematic review and meta-analysis included studies on the prevalence of CBPP in Ethiopia. The literature search was conducted from January 2024 to February 2024. Initially, 4157 articles were identified using English language and cattle participant criteria. Of these, 2896 were excluded because their titles or abstracts indicated that they were not relevant. The remaining 1261 studies were further scrutinized, with 256 found to be duplicates or unsuitable. A total of 1005 full-text papers were reviewed for eligibility on the basis of established criteria, leading to the inclusion of 23 studies in the review and meta-analysis. The remaining 982 articles were excluded because of issues such as the study area and other factors, as detailed in Fig. 1.

3.2. Study characteristics

Table 1 presents the characteristics of the 23 studies included in this systematic review and meta-analysis. All studies were cross-sectional and were conducted across various regions of Ethiopia, with sample sizes ranging from 384 to 38,187. The studies were published between 2004 and 2023. Each study employed similar diagnostic methods and designs, specifically using cross-sectional and C-ELISA techniques.

3.3. Quality assessment results

This review assessed the quality of a range of studies, which varied from low to moderate. None of the 23 quantitative studies met the criteria established by the AXIS tool, which evaluates details related to risk factors and outcome variables. Notably, all studies used a well-defined method for estimating sample size. The majority, specifically 20 out of 23 (86 %), employed the simple random sampling method described by Downes, Brennan, Williams, & Dean, 2016. Additionally, all 23 studies (100 %) successfully sourced a sample frame from a population that was closely aligned with the target or reference population. Among the studies, 17 (approximately 74 %) met the criteria for six out of the 20 AXIS questions, including aims/objectives, definition of the target/reference population, internal consistency of results, authors' justification of results, sample size justification, and appropriate analytical techniques.

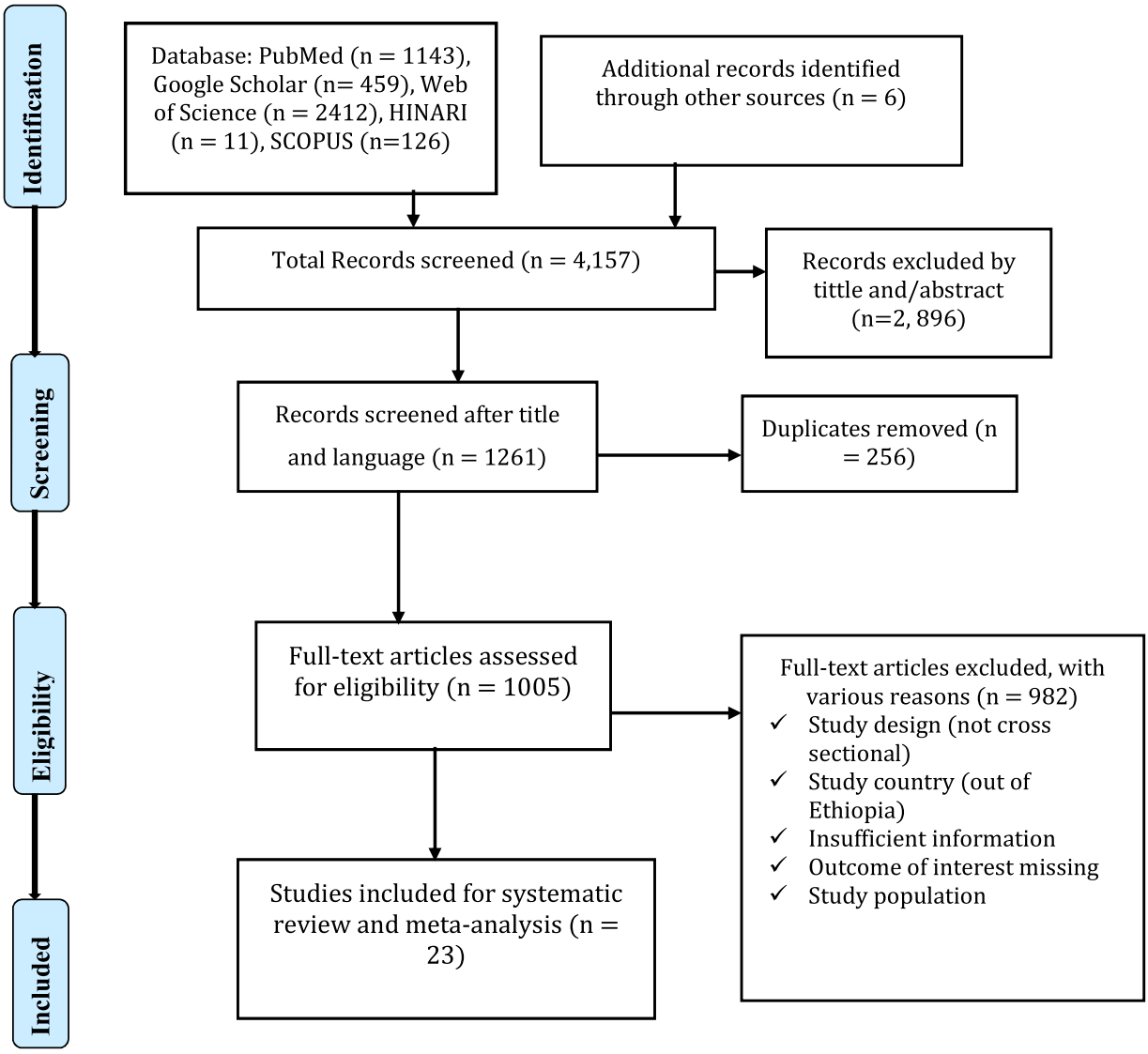


Fig. 1. Flowchart of study selection for a systematic review and meta-analysis of the seroprevalence of CBPP in Ethiopia.

3.4. Meta-analysis

The current meta-analysis used 23 English-language studies. As a result, the overall seroprevalence of CBPP was 13 % (95 % CI: 7–21 %). Statistically significant differences were found between studies regarding CBPP seroprevalence (I^2=99 %, Q test = 4050.42.13, df = 22, $p < 0.001$). Despite significant heterogeneity between studies, the studies were roughly weighted equal, with individual study weights ranging from 4.1 % to 4.4 % (Fig. 2).

3.5. Subgroup meta-analysis results

In view of the considerable heterogeneity, subgroup analysis was conducted to identify the source of heterogeneity between studies. This analysis considered various stratification as moderators, such as study year, age category, sex, breed of animals, body condition of animals, herd size and sample size category. To assess the heterogeneity within subgroups, a mixed effects model was employed, which combined study effects via the random effects model. Furthermore, the fixed effects model was used to test whether the effects significantly differed between subgroups.

3.5.1. Comparing regional prevalence

As shown in Fig. 3, the highest seroprevalence of CBPP was recorded in eastern Ethiopia (18 %, 95 % CI: 9–34 %), followed by western Ethiopia (15 %, 95 % CI: 8–27 %) and northern Ethiopia (14 %, 95 % CI: 4–37 %). These prevalence rates are somewhat similar across these regions, with eastern Ethiopia showing the highest (18 %) and northern Ethiopia the lowest (14 %). However, the overlap in confidence intervals suggests that these differences might not be statistically significant. The confidence intervals for eastern and western Ethiopia overlap (9–34 % and 8–27 %, respectively). For northern Ethiopia, the wide confidence intervals (4–37 %) indicate a high degree of variability. This may be due to the smaller sample size or greater variability in the data from northern Ethiopia.

3.5.2. Comparing pre-2016 and post-2016 prevalence

Subanalysis on the basis of study year revealed statistically significant heterogeneity when the years were categorized into two groups: pre-2016 and post-2016. The results presented in Fig. 4 show that the subgroup analysis was performed by categorizing the study years. Accordingly, the seroprevalence of CBPP was greater in studies conducted after 2016 (16 % (95 % CI: 9–26 %) than in studies conducted before 2016 (8 % (95 % CI: 3–19 %)) (Table 2). A test for subgroup differences confirmed a statistically significant subgroup effect (Q =

Table 1
Descriptive statistics of the studies included in the final systematic review and meta-analysis.

Author	Study year	Study location	Diagnostic test	Sample size	Positive sample	Not event	Event rate
Tesfaye Bekele, 2020	2019	Western Ethiopia	C-ELISA	384	13	371	0.0339
Y. Mamo et al., 2018	2015	Northern Ethiopia	C-ELISA	384	31	353	0.0807
Alemayehu et al., 2015	2011	Southern Ethiopia	C-ELISA	38,187	150	38,037	0.0039
Geresu et al., 2017	2016	Western Ethiopia	C-ELISA	384	25	359	0.0651
Atnafie et al., 2015	2014	Northern Ethiopia	C-ELISA	384	30	354	0.0781
Teklue et al., 2015	2013	Eastern Ethiopia	C-ELISA	384	46	338	0.1198
Neggasa et al., 2020	2018	Western Ethiopia	C-ELISA	384	33	351	0.0859
G. Daniel et al., 2016	2013	Western Ethiopia	C-ELISA	386	110	276	0.285
T. Ebisa et al., 2015	2014	Eastern Ethiopia	C-ELISA	400	127	273	0.3175
Negash & Dubie, 2021	2018	Western Ethiopia	C-ELISA	420	158	262	0.3762
Wolde et al., 2018	2017	Eastern Ethiopia	C-ELISA	421	192	229	0.4561
G. Malicha et al., 2017	2016	Eastern Ethiopia	C-ELISA	462	117	345	0.2532
Lemu & Worku, 2017	2013	Southern Ethiopia	C-ELISA	502	7	495	0.0139
Aliy et al., 2017	2015	Western Ethiopia	C-ELISA	545	300	245	0.5505
Molla et al., 2021	2011	Southern Ethiopia	C-ELISA	751	97	654	0.1292
Mosisa et al., 2023	2019	Eastern Ethiopia	C-ELISA	768	110	658	0.1432
Gizaw et al., 2004	2003	Western Ethiopia	C-ELISA	793	82	711	0.1034
Atnafie et al., 2015	2014	Eastern Ethiopia	C-ELISA	1086	65	1021	0.0599
Kassaye & Molla, 2013	2010	Eastern Ethiopia	C-ELISA	3111	124	2987	0.0399
Teshome et al., 2024	2023	Western Ethiopia	C-ELISA	498	46	452	0.0924
Negash & Dubie, 2021	2019	Northern Ethiopia	C-ELISA	420	158	262	0.3762
W. Kebede et al., 2022	2019	Southern Ethiopia	C-ELISA	715	162	553	0.2266
Fulasa et al., 2020	2019	Western Ethiopia	C-ELISA	604	204	400	0.3377

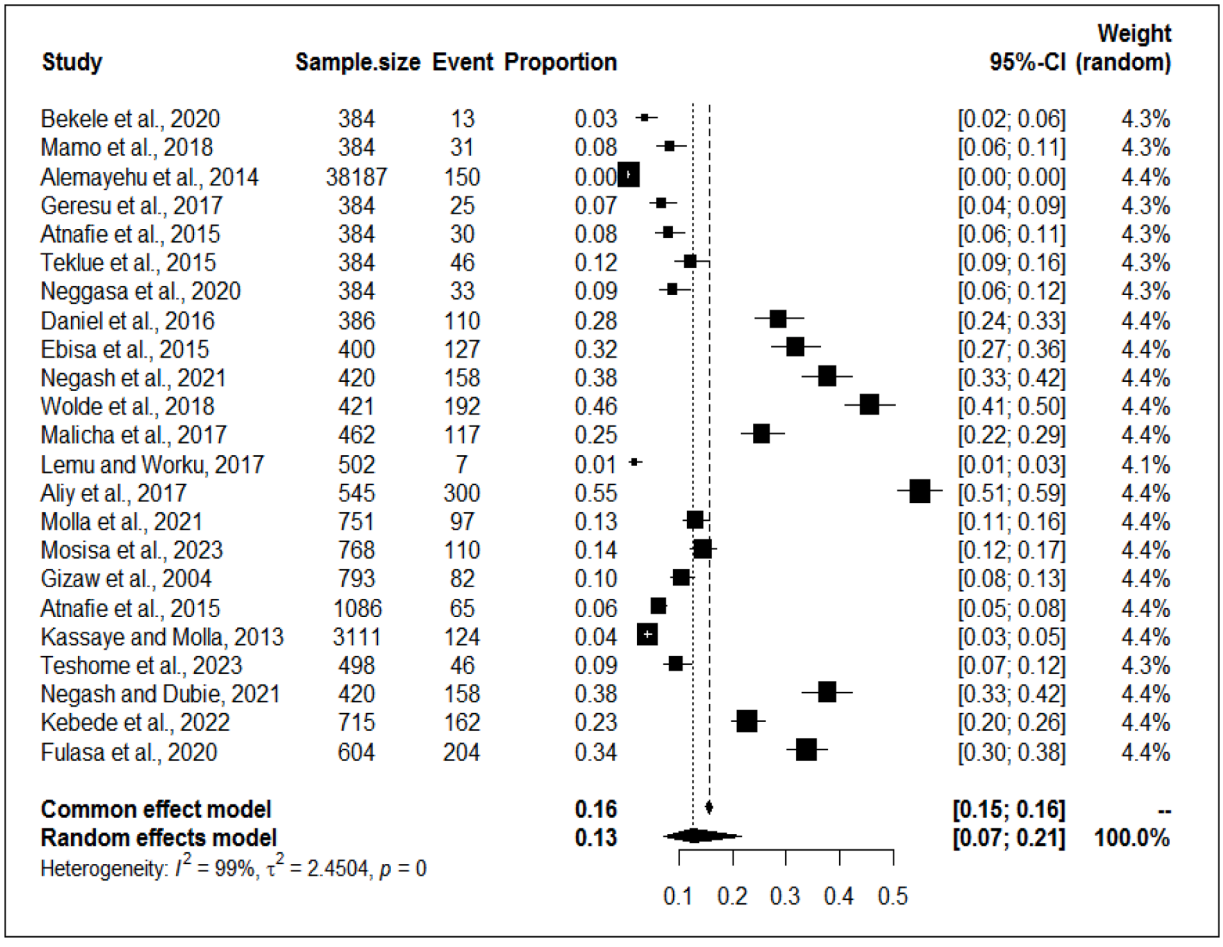


Fig. 2. Forest plot for CBPP seroprevalence estimates in Ethiopia.

3.80; DF=1; $P < 0.017$), with substantial heterogeneity of I^2=100 % and 98 % for the post-2016 and pre-2016 year categories, respectively. However, the high heterogeneity in both time periods suggests that there is considerable variability in the prevalence estimates, which may be influenced by various factors.

3.5.3. Prevalence of CBPP with different demographic moderators

The pooled prevalence of CBPP was estimated at 18 % (95 % CI:

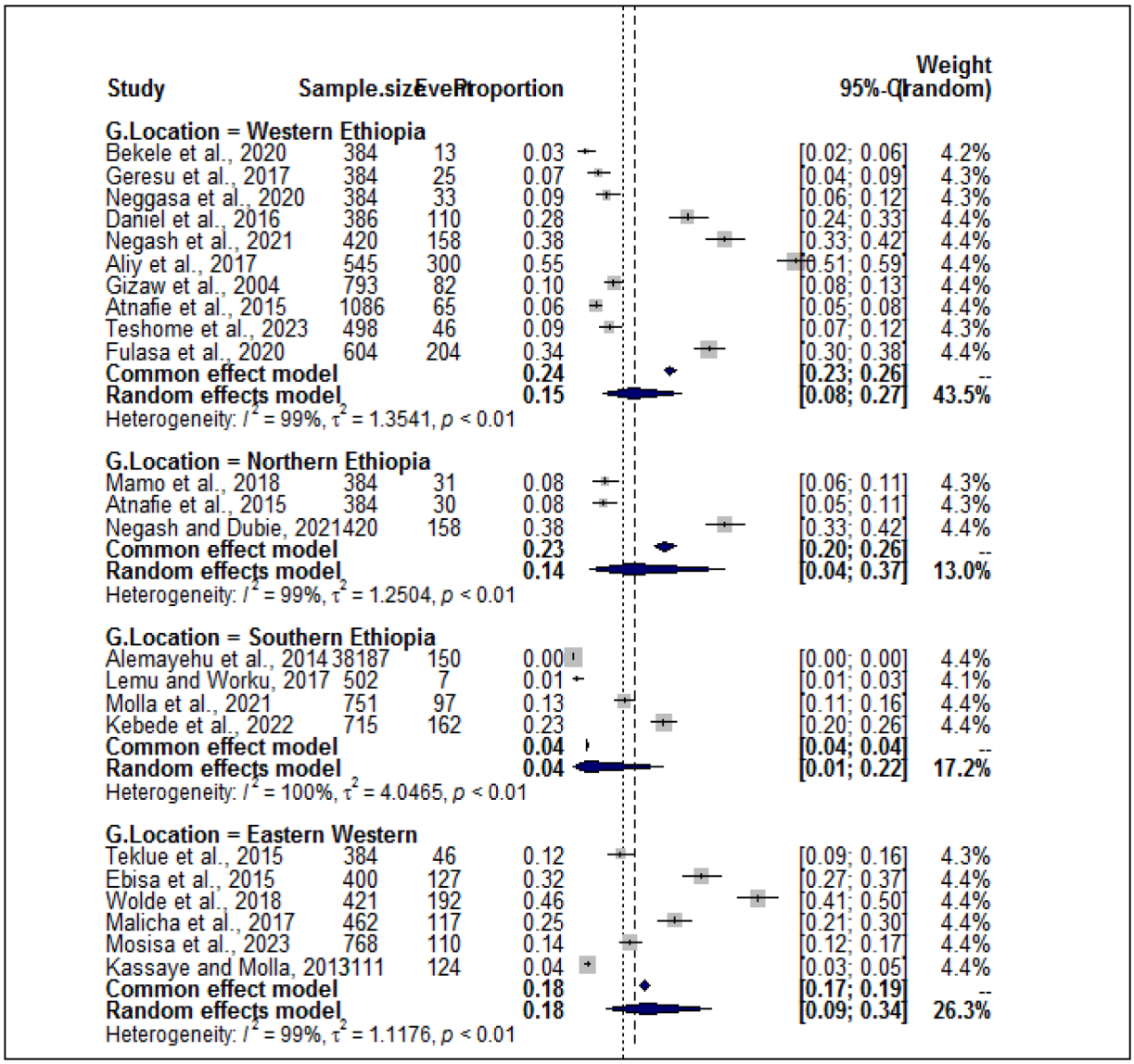


Fig. 3. Forest plot depicting the subgroup seroprevalence of CBPP across different study locations.

10–29 %) for local breeds, whereas it was 26 % (95 % CI: 12–47 %) for crossbreeds. Among the different age groups, the prevalence was 13 % (95 % CI: 7.5–23.6 %) for younger animals and 18 % (95 % CI: 11.9–27.3 %) for adults. The prevalence was 19 % (95 % CI: 11.6–30.6 %) in males and 16 % (95 % CI: 10.1–23.1 %) in females. When examining CBPP incidence in relation to herd size, large herds had a prevalence of 39 % (95 % CI: 36.2–41.6 %), whereas small herds had a prevalence of 29 % (95 % CI: 26.9–32.3 %). Additional details on the estimates and their statistical significance, including factors such as agroecology and body condition, are provided in Table 2.

3.6. Assessment of publication bias and small study effects

Publication bias and small study effects were assessed via funnel plot observation and Egger's test, respectively. The results, which compare effect estimates against their standard errors, indicated no significant publication bias [b = 88.0940 (CI: 27.39, 148.79), p = 0.6180] (Fig. 5). Furthermore, we confirmed that there was no evidence of missing studies that could be amalgamated by Duval and Tweedie's trim-and-fill method (Fig. 6). This implies that the estimated number of missing studies on the right side is 0 (SE = 2.7974).

3.7. Meta-regression

We used univariate meta-regression analysis to identify potential sources of variation in pooled prevalence, considering study year, study location, age, herd size, and sample size as potential factors. Each variable was analyzed separately in a meta-regression analysis. For this analysis, study year, location, age, and sample size were treated as categorical variables. The occurrence of CBPP was significantly (p = 0.02094) associated with the herd level of cattle. As indicated in Table 3, the occurrence of CBPP decreased by 0.59 for individual animals in the small herd size group compared with those in the large herd size group. This implies that the prevalence of CBPP was also 45 % greater (coefficient =−0.59, which is equal to OR=0.55) in the presence of a large herd than in the presence of a small herd. Likewise, the body condition of the animals was also statistically associated with the occurrence of CBPP (p = 0.0191). The prevalence of CBPP in poor-body-weight animals was 0.85 higher than that in good-body-weight animals. The odds of CBPP occurrence may be 2.34 times greater in poor animals than in good animals. Multivariable analysis was not possible because the moderators did not have similar effect sizes and were difficult to analyse in combination.

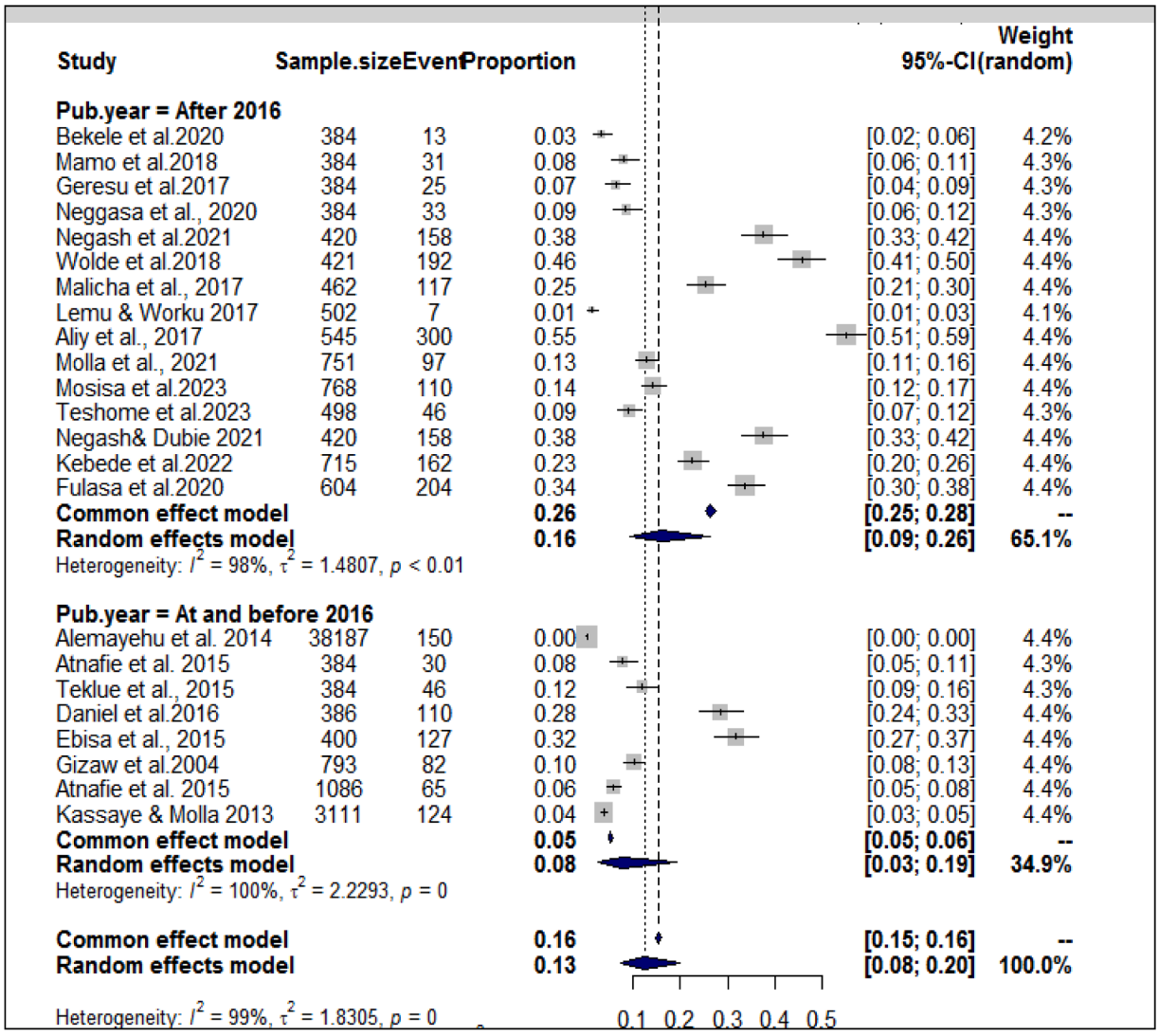


Fig. 4. Forest plot depicting the subgroup seroprevalence of CBPP by different publication years.

4. Discussion

Contagious bovine pleuropneumonia (CBPP) is the most significant transboundary infectious disease affecting cattle populations. This disease has major economic consequences for the nation. To our knowledge, this is the first meta-analysis of pooled estimates of CBPP in Ethiopia, indicating a pivotal contribution to the existing knowledge base. The data used for this meta-analysis were drawn from a comprehensive review published from 2004 to 2023. Notably, a total of 982 studies were excluded because of incompatible research designs, absence of the outcome of interest, unsuitable study settings, and insufficient sample sizes. To mitigate potential sources of variability, the selection criteria favoured studies employing similar diagnostic methodologies (C-ELISAs) and study designs (cross-sectional). Furthermore, the limited availability of crucial data points across articles and the influence of various moderating factors decreased the pool of studies eligible for inclusion in the final meta-analysis. Consequently, the final systematic review and meta-analysis included only 23 articles.

The pooled seroprevalence of CBPP in this study was 13.0 % (95 % CI: 7–21 %). This finding is lower than several earlier studies conducted across Ethiopia, which reported higher rates, such as 25.32 % to 55.05 % (G. Malicha et al., 2017; Aliy et al., 2017; T. Ebisa et al., 2015). More recent studies also reported seroprevalence values ranging from 13.95 % to 37.62 % (Neggasa et al., 2020; Tola et al., 2021). In contrast, our results are higher than those reported by Y. Mamo et al. (2018) and Admassu et al. (2015), who found seroprevalence rates of 8.07 % and 12.92 %, respectively. This wide variation in the seroprevalence of CBPP reported from different parts of Ethiopia could be due to differences in agroecology, management systems, population density and the types of tests employed to evaluate its prevalence (Schubert *et al.*, 2011). The results of the present study on the seroprevalence of CBPP differ more logically from those of previously reported individual studies in the country, as it reports the pooled seroprevalence of the disease at the national level.

When comparing seroprevalence rates internationally, the pooled prevalence of CBPP infection was 13 %, which is notably lower than the rates of 50.5 % reported in Sudan (Hussien et al., 2024), 17.5 % reported in Angola (Daniel et al., 2017), 18.11 % reported in Mali (Séry et al., 2015), and 39 % reported in Somali (G.M. Gizaw, 2004). The high prevalence rate in Sudan might be attributed to the use of less effective control measures, higher cattle densities, or more favourable environmental conditions for CBPP transmission. Conversely, this pooled prevalence is substantially greater than the 4.15 % reported in Niger (Yansambou et al., 2018) and the 3.4 % reported in Cameron (Francis et al., 2018) via polymerase chain reaction techniques. Similarly, in Tanzania, (Swai et al., 2013) reported a CBPP prevalence of 0.91 %, whereas a prevalence of 3.6 % was reported in Zambia (Phiri, 2006), 9.7 % in south western Kenya (Schnier et al., 2006) and 10.65 % in Kwara

Table 2
Pooled effect size estimates of CBPP, stratified by subgroups.

Moderators	K	Category	N	Case	ES (95 %CI)(RE)	Heterogeneity			Test for subgroup differences (RE)	
						I^2(%)	τ^2	p value	Q	p value
Pooled prevalence	23	Overall	52,373	2387	0.13[0.07;0.201]	99	2.45	0.00	4050	<0.0001
Herd size	8	Small	1272	549	0.29 [0.269; 0.323]	97.1	1.03	<0.001	22.18	0.024
		Large	1571	343	0.39 [0.362; 0.416]	93.7	0.53	<0.001		
Body condition		Poor	1412	414	0.25 [0.190; 0.345]	88.8	0.37	<0.001	5.92	0.015
	12	Good	2230	300	0.12[0.071;0.205]	92.7	1.07	<0.001		
breed	8	Local	3394	687	0.18 [0.103; 0.292]	95.7	0.82	<0.001	0.65	0.418
		Exotic	578	151	0.26 [0.119; 0.475]	86.8		<0.001		
Age	18	Young	4294	596	0.13 [0.075; 0.236]	96.8	1.88	<0.001		0.405
		Adult	6062	1220	0.18 [0.119; 0.273]	97.8	1.5	<0.001	0.69	
Sex	18	Male	3205	764	0.19 [0.116; 0.306]	95.9	162	<0.001		
		Female	5376	1113	0.16 [0.101; 0.231]	96.8	1.08	<0.001	0.45	0.5023
Agro-ecology	6	Lowland	789	389	0.42[0.234;0.520]	92.3	1.7	<0.001	26.4	0.043
		Highland	567	145	0.23[0.082;0.402]	94.0	0.34	<0.001		
Study year	8	Post-2016	44,731	734	0.16[0.094; 0.26]	98.4	1.83	0.00	3.80	0.017
	15	Pre-2016	7642	1613	0.08 [0.029; 0.192]	99.6	1.48	<0.01		
Location	3	Northern	1188	219	0.14[0.044; 0.374]	99.0	1.25	<0.01	2.47	0.48
	6	Eastern	5546	716	0.18 [0.087; 0.34]	99.0	1.12	<0.01		
	10	Western	5484	1036	0.15[0.079; 0.267]	99.0	1.35	<0.01		
	4	Southern	40,155	416	0.04[0.006; 0.223]	100.0	4.01	<0.01		
Sample size	7	300–400	2990	288	0.09 [0.055; 0.149]	95.7	0.51	<0.001	14.13	0.0014
	6	400–500	2621	798	0.29 [0.186; 0.428]	96.7	0.53	<0.001		
	10	>500	47,062	1301	0.089[0.033; 0.218]	99.7	2.83	<0.001		

K= Number of included studies, *N*=Total number of cattle population, Case = C-ELISA positive Animals, RE=Random effect.

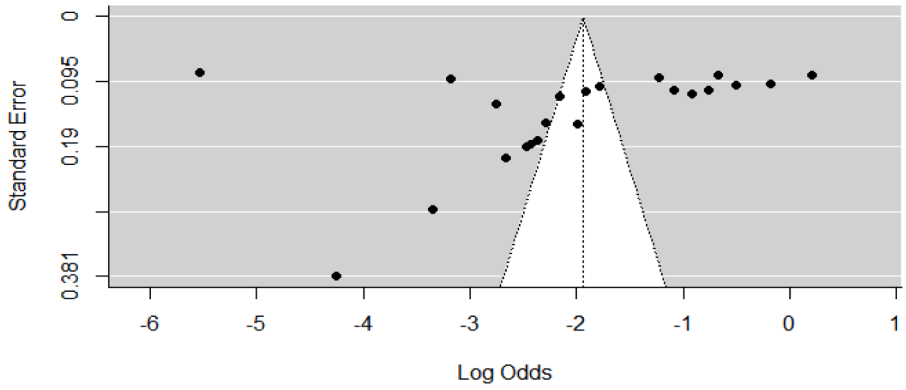


Fig. 5. Funnel plot showing publication bias and small study effects.

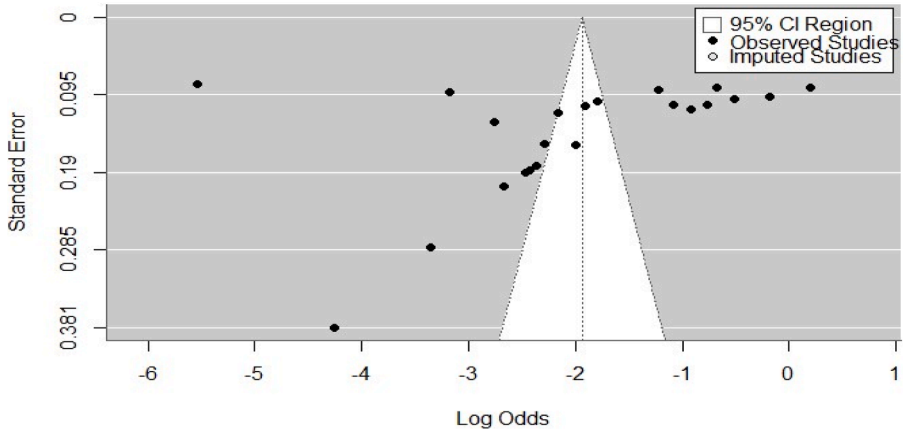


Fig. 6. Trim-and-fill funnel plot showing no missed studies (no imputed studies).

state, Nigeria (Olabode et al., 2013). The variations in seroprevalence rates could be attributed to the diverse agroecological settings of the study areas, variations in animal management practices, population densities, production systems, and methodologies employed for assessing seroprevalence(Alemayehu et al., 2015a). Moreover, different diagnostic techniques and sampling methods can lead to variations in

Table 3
Univariate meta-regression.

Moderator		N	Coefficient &95 %CI	R^2 (%)	Test for Residual Heterogeneity (QE&P Value)	Test of Moderators (QM& p value)
Age	Adult	6062	**Ref.**			
	Young	4294	−0.31[−1.14,0.52]	0.00	1286.180, < 0.0001	0.5509, 0.4580
Breed	Cross	578	**Ref.**	0.00	216.2021, < 0.0001	0.7626, 0.3825
	Local	3394	−0.49[−1.60,0.62]			
Herd size	Large	1571	**Ref.**			
	small	1272	−0.59[−1.53,0.34]	21.23	349.52, < 0.0001	1.5754,0.02094
BCS	Good	2230	**Ref.**			
	Poor	1412	0.85[0.138, 1.55]	17.55	248.12, < 0.0001	5.4905, 0.0191
Sex	Female	5376	**Ref.**			
	Male	567	0.26[−0.504, 1.03]	0.00	945.23, < 0.0001	0.4488, 0.5029
Location	E	5546	**Ref.**			
	W	5484	0.053[−1.248,1.35]	6.28	2861.67, < 0.0001	4.5321, 0.209
	N	1188	−0.12[−1.902,1.66]			
	S	40,155	−1.53[−3.161, 0.08]			
Study year	Post-2016	44,731	**Ref.**			
	Pre-2016	7642	−0.83[−1.918,0.25]	19.62	3369.89, < 0.0001	2.28,0.01303

E= Eastern, *W*= Western, *N*= Northern, *S*= Southern, *N*= Total number of samples.

reported prevalence rates. For instance, studies using serological methods tend to report different rates compared to those utilizing molecular techniques such as PCR. This variation underscores the importance of standardizing diagnostic approaches to ensure more consistent prevalence estimates.

In terms of locations, the prevalence of CBPP varied across study locations, with higher seroprevalence reported in Eastern Ethiopia (18 % (95 % CI: 9 %, 34 %)), and the variation was statistically significant ($p < 0.05$). In addition, the seroprevalence of CBPP was 15 % (95 % CI: 8 %, 27 %) in western Ethiopia, 14 % (95 % CI: 4 %, 37 %) in northern Ethiopia, and 4 % (95 % CI: 1 %, 22 %) in southern Ethiopia. The current findings in Eastern Ethiopia are in line with the reports of Alemayehu et al. (2015) and T. Ebisa et al. (2015). The variation observed between the different study locations and individual studies in the current study might be due to differences in cattle population densities and management practices between the different areas of the country. Additionally, socio-economic factors, including farmers' access to veterinary services and education on disease management, can play a critical role in prevalence.Farmers often keep many animals on extensive grazing lands. This increases their animals' chances of encountering infected cattle, especially as they travel long distances for pasture and water. In addition, animals are more confined to the watering point, so CBPP can be easily transmitted through aerosols to susceptible animals. Therefore, region-specific strategies that enhance the management of grazing lands and promote sustainable practices are essential. This might include the establishment of designated grazing areas and the promotion of mixed farming practices to minimize contact between herds.

Moreover, the prevalence of CBPP varied between the study years, with higher seroprevalence recorded in studies conducted after 2016 (16 % (95 % CI: 9.0, 26.0), and the variation was statistically significant ($p < 0.05$). Moreover, the seroprevalence of CBPP was 8 % (95 % CI: 3.0, 19.0; $p \leq 0.001$) in studies conducted before and before 2016. While the statistical significance indicates that these changes are unlikely due to chance, the real-world implications are critical. The increase in CBPP prevalence highlights a growing risk for cattle populations in Ethiopia, potentially leading to significant economic losses for farmers and impacting food security. With seroprevalence more than doubling, there is an urgent need for targeted control measures. This trend suggests the disease is becoming more entrenched, likely due to increased animal density, management changes, or environmental factors. Immediate action is required from stakeholders, including enhanced vaccination efforts, improved surveillance, and community education on disease management practices.

This higher prevalence could indicate either a true increase in disease occurrence or enhanced detection and reporting capabilities. This may also be linked to the variation observed between the different study years in the current study, which might be due to differences in the number of studies conducted between the two categories. Environmental changes, such as droughts, can force animal owners to concentrate their animals around limited water sources, further increasing the risk of disease spread. Moreover, variations in livestock management practices, including potential neglect of veterinary care due to economic pressures, may have exacerbated the situation. Fluctuations in vaccination coverage, regional conflicts that increase livestock mobility, and the emergence of more virulent pathogen strains also play critical roles.

Among the potential predisposing factors assessed were age (young, 13 %; adult, 18 %). Seropositivity in adults was slightly greater than that in young animals. This difference in seroprevalence between the two age categories could be attributed to young animals being tethered within the homestead when adult cattle graze. The goal is to prevent them from exhausting from long-distance travel in search of water and pasture where they contact herds from other households. The higher prevalence rate in large herds (39 %) suggests that larger herds may experience a greater burden of CBPP. This could be due to factors such as increased animal density, increased risk of disease transmission, or potentially less effective disease management practices. In such contexts, it is crucial for livestock owners to adopt more rigorous disease management practices. Implementing measures such as improved monitoring, regular health checks, and stricter biosecurity protocols could significantly mitigate the risk of outbreaks. Additionally, educating farmers about the importance of maintaining lower stocking densities and rotational grazing systems could help reduce the likelihood of transmission among animals. In general, the present meta- and sub-analyses demonstrated that the pooled prevalence of CBPP significantly increased in Ethiopia after 2016. To effectively control and eradicate the disease in Ethiopia, livestock owners, animal health professionals, and governmental authorities must consider the lowland areas of the eastern part of the country.

First, enhancing surveillance and reporting systems is crucial, involving training local veterinarians and community animal health workers for timely detection of cases. Implementing comprehensive vaccination programs in high-prevalence regions will ensure accessibility and affordability. Educating farmers on best management practices, including biosecurity and maintaining lower stocking densities, is vital for reducing transmission risks. Engaging local communities through farmer cooperatives fosters collective responsibility and knowledge sharing. Establishing controlled grazing practices, such as designated areas and rotational grazing, can minimize herd contact. Improving access to veterinary services in rural areas will provide farmers with necessary treatments and diagnostics. Continued research into effective control measures tailored to regional needs is critical, along with a framework for monitoring and evaluating these strategies. By adopting these measures, stakeholders can significantly reduce the

impact of CBPP and enhance cattle health and productivity in Ethiopia

This study has some important limitations that could affect the interpretation of the findings. Firstly, it included only 23 studies, with a greater concentration of research from northern Ethiopia and a limited number from southern Ethiopia. This unequal distribution may lead to biased estimates of the prevalence of Contagious Bovine Pleuropneumonia (CBPP), as regions with fewer studies may not accurately reflect the overall situation. Consequently, this could distort our understanding of disease dynamics and limit the generalizability of the findings across the country. Secondly, the limited number of studies restricted our ability to conduct thorough subgroup analyses. As a result, we may overlook significant variations in seroprevalence related to factors such as agroecological conditions or management practices in different regions. This limitation may hinder our ability to identify targeted control strategies for specific areas. Additionally, even after performing subgroup analyses, the original data still revealed a considerable degree of heterogeneity between trials. This variability suggests that differences in study sampling methodology or local conditions could affect the reported prevalence rates. Such heterogeneity complicates the interpretation of pooled estimates and raises questions about the reliability of the overall conclusions. Moreover, the study did not account for all factors influencing CBPP prevalence in Ethiopia, which could lead to an incomplete understanding of the disease's epidemiology. This limitation is further underscored by the funnel plot of Egger's test statistics, indicating potential publication bias and the influence of smaller studies. Such biases can distort the evidence base, resulting in either an overestimation or underestimation of CBPP prevalence.

5. Conclusion and recommendations

In the meta-analysis, the pooled prevalence of CBPP was estimated to be 13 %, with a 95 % confidence interval of 7 % to 21 % across Ethiopia. The 13 % prevalence indicates a concerning baseline level of infection across the country, suggesting that CBPP remains a significant threat to cattle populations. Furthermore, the reported seroprevalence in the country is significantly associated with the country's study location, with the greatest prevalence recorded from the eastern part of the country, where a greater cattle population of the country is maintained. Furthermore, analysis revealed a significant increase in the seroprevalence of CBPP in studies conducted after 2016, with a prevalence rate of 16 %, compared to 8 % in studies conducted before 2016. The increase to 16 % in more recent studies may reflect worsening conditions for disease control. This increase may stem from factors such as closer animal contact due to changes in management practices, environmental pressures like drought, economic challenges affecting veterinary care, increased livestock mobility from regional conflicts, and improved detection methods that enhance reporting accuracy. The implications of this trend underscore the need for a reassessment of current CBPP control measures and suggest a potential shift in disease dynamics. The higher seroprevalence of CBPP in large herds (39 %) than in small herds (29 %) highlights a potential difference in disease burden on the basis of herd size. This finding aligns with the observations of Alemayehu et al. (2015) and T. Ebisa et al. (2015), who noted that larger herds are often at greater risk due to increased animal density, which can facilitate disease transmission. This suggests that larger herds might be at greater risk or face different challenges in managing CBPP. As a result, close monitoring of herd size and production area is necessary, as its occurrence may result in international restrictions on the trade of animals and animal products, reducing the country's export earnings and endangering pastoralists' livelihoods and the national economy. Furthermore, an efficient vaccination policy must be explored, as it is the only feasible method of controlling CBPP in the country if it is practicable with movement restrictions.We suggest the establishment of robust surveillance systems to effectively monitor disease prevalence and assess the impact of vaccination efforts in real-time. Additionally, engaging the community through educational workshops for farmers on biosecurity practices and the significance of maintaining lower stocking densities will be vital in mitigating transmission risks. Strengthening collaborations with local veterinary services will further enhance disease management and ensure timely treatment for infected animals. By implementing these measures, we aim to increase the practical value of our findings and offer clearer guidance to stakeholders.We also suggest that policymakers consider integrating CBPP control measures into broader public health strategies, promoting initiatives that facilitate better access to veterinary care and vaccination programs. Furthermore, these findings highlight the need for continued research to explore the epidemiology of CBPP, particularly in relation to changing environmental and management practices. Future studies could focus on the effectiveness of specific interventions and the development of more resilient livestock systems. By incorporating these elements, we aim to provide a comprehensive view of the implications of our findings and guide future efforts in addressing CBPP.

Competing interests

The authors declare that there are no direct or indirect conflicts of interest that may call the validity of this study into question.

Consent for publication

All the authors have read and approved the final manuscript.

Availability of data and material

All the data generated or analysed during this study are available upon the request of the corresponding author.

Funding

Not applicable.

Ethics statement and consent to participate

Not applicable.

CRediT authorship contribution statement

Melkie Dagnaw Fenta: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Formal analysis, Data curation, Conceptualization. **Marshet Bazezew:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization. **Wassie Molla:** Writing – review & editing, Visualization, Supervision, Formal analysis. **Mebrie Zemene Kinde:** Writing – review & editing, Writing – original draft, Validation, Methodology. **Bemrew Admassu Mengistu:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Haileyesus Dejene:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Not applicable.

Supplementary materials

Supplementary material associated with this article can be found, in

the online version, at doi:10.1016/j.vas.2024.100410.

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