

Systematic review

Brucellosis seroprevalence among high-risk occupational groups in Nigeria: a systematic review and meta-analysis (2001–2025)

Christopher O. Fakorede^{1,2*}, Kehinde A. Fasure^{2,3}, Ana Cristina Ferreira^{4,5,6}, Sandra C. Gonçalves⁴, Mohamed I. A. Hassan⁷, Peter F. Agbaye⁸, Kehinde O. Amisu⁹ and Kabiru O. Akinyemi⁹

¹Department of Biological Sciences, Microbiology Unit, Lagos State University of Science and Technology, Ikorodu, Lagos, Nigeria

²Centre for Molecular Epidemiology of Enteric and ESKAPE Pathogens, Lagos, Nigeria

³Department of Medical Laboratory, Lagos State College of Health Technology, Yaba, Lagos, Nigeria

⁴Laboratory of Bacteriology and Mycology, Animal Health Unit, INIAV, Oeiras, Portugal

⁵BioISI, Faculty of Sciences, University of Lisbon, Portugal

⁶I-MVET, Universidade Lusófona, Lisboa, Portugal

⁷Faculty of Medicine, Friedrich-Schiller University, Jena, Germany

⁸Department of Animal Production, Lagos State University of Science and Technology, Ikorodu, Lagos, Nigeria

⁹Department of Microbiology, Lagos State University, Ojo, Lagos, Nigeria

*Corresponding author: Christopher O. Fakorede, fakorede.co@lasustech.edu.ng

Article history: Received 8 July 2026; Accepted 20 September 2026; Available online 25 September 2026

Article information: Fakorede CO et al., 2026. *One Health Microbiol. Infect.* Vol. 2, No. 1: 239–252. <https://doi.org/10.66585/ohmi.2026.2.0032>



Abstract

Brucellosis is a neglected occupational zoonosis in Nigeria, driven by a large livestock sector and widespread exposure in high-risk settings. This systematic review and meta-analysis, conducted in accordance with the PRISMA 2020 guidelines, synthesizes evidence from 2001 to 2025 to estimate group-specific occupational seroprevalence of brucellosis in Nigeria. We systematically searched PubMed, Scopus, Medline, Web of Science, African Journals Online, Embase, and Google Scholar, using ResearchGate as a supplementary source of gray literature, for studies reporting laboratory-confirmed human seroprevalence among occupational and nonoccupational comparator groups. We computed pooled estimates with 95% confidence intervals (CIs) using a random-effects (DerSimonian–Laird, logit-transformed) meta-analysis. The final corrected dataset comprises 15 studies from 10 named Nigerian states and the Federal Capital Territory (FCT), spanning 5 of Nigeria's 6 geopolitical zones (North-Central, North-East, North-West, South-East, South-West); no eligible studies from South-South. Overall pooled seroprevalence was 12.8% (95% CI: 8.6–18.6%; $I^2 = 94.0\%$; raw seroprevalence: 13.6%, 477/3,508). Among nine occupational group studies, pooled seroprevalence was 13.7% (95% CI: 7.8–22.7%), with the highest among abattoir/slaughterhouse workers (27.2%, 95% CI: 21.3–34.1%), followed by livestock/cattle farmers (10.3%), nomadic herdsman/pastoralists (10.0% and 0.7%, two divergent single-study estimates), and butchers (5.2%). Six non-occupational comparator studies pooled to 11.4% (95% CI: 6.1–20.5%), ranging from 3.8% among internally displaced persons to 28.7% among febrile/malaria patients in Enugu (South-East) and 19.0% among women with miscarriage in Zaria. A high-quality-only sensitivity analysis ($NOS \geq 7/9$) yielded 17.1% (95% CI: 11.0–25.7%). Key risk factors included handling aborted fetal tissue, raw dairy consumption, lack of personal protective equipment (PPE), and unregulated livestock migration. Abattoir workers remain the clearest, most robustly supported occupational risk group in the Nigerian evidence base and should be the priority target for mandatory PPE enforcement, targeted screening, and public health messaging.

Keywords: Brucellosis, High-risk groups, Nigeria, Occupational exposure, One Health, Seroprevalence, Zoonosis

Introduction

Brucellosis is caused by Gram-negative, facultative intracellular bacteria of the genus *Brucella* (*B.*). It is the most common bacterial zoonosis worldwide, with about 2.1 million new human infections annually [1, 2]. The World Health Organization (WHO) classifies it as a neglected tropical zoonosis, and notes that it disproportionately affects Sub-Saharan Africa, the Middle East, and Central Asia [1, 3, 4]. Of the more than twelve recognized *Brucella* species, four are established human pathogens, namely *B. melitensis*, *B. abortus*, *B. suis*, and *B. canis*, with *B. melitensis* causing the greatest burden of severe disease globally [5, 6, 7]. Occupational exposure accounts for most documented human cases: livestock farmers, abattoir workers, herders, butchers, veterinarians, and laboratory personnel face elevated risk through skin wounds, mucosal exposure, aerosol inhalation, and ingestion of contaminated animal

products [1, 8, 9, 10, 11, 12]. *Brucella*'s low infectious dose (10–100 organisms) makes slaughter settings especially hazardous for unprotected workers [13].

Nigeria presents a particularly high-risk occupational environment, reflecting both its large population of over 220 million and an extensive livestock sector comprising an estimated 54.81 million cattle, 138.95 million goats, 64.93 million sheep, and 683.68 million poultry, based on the most recent national agricultural census [14]. The common consumption of raw fermented dairy (nono) in northern states exposes the workforce to multiple risk pathways simultaneously. Abattoir animals are rarely screened ante-mortem, and personal protective equipment (PPE) is neither mandated nor enforced. Nomadic Fulani herders move infected animals across zones without veterinary oversight [15, 16]. Brucellosis remains consistently underreported and is frequently misdiagnosed as malaria because of its nonspecific

presentation [13, 17]. Most Nigerian seroprevalence studies focus on single occupational groups in isolated states and do not pool estimates.

Occupational brucellosis has been recognized since 1887, when Sir David Bruce first isolated the causative organism from British soldiers stationed in Malta [18]. The goat's-milk transmission route was not established until 1905, when Themistocles Zammit demonstrated that unpasteurized goat's milk was the vehicle of infection [19]. The WHO classifies brucellosis as an occupational hazard for those working in the livestock sector, including farmers, butchers, and veterinarians [20]. It causes systemic effects such as fever, arthralgia, and fatigue, and has the potential for chronic relapse and substantial treatment costs [21], disproportionately affecting developing countries, where an estimated 3.5 billion people are at risk [22]. Across Sub-Saharan Africa, reported occupational seroprevalence varies widely: 44% among Kenyan herders versus 3.0% nationally [23, 24], 17% in Uganda [25], 15.8–31.5% among Ethiopians [26], and 41% in Tanzania [27], reflecting genuine epidemiological differences and methodological heterogeneity.

Systematic investigation of occupational brucellosis in Nigeria has expanded since 2001, encompassing abattoir workers in Abuja [28], Ibadan [29], and Ilorin [30]; livestock workers in Bauchi [31] and Maiduguri [16, 32]; and pastoralist and prison-farm cohorts in Sokoto [33, 34]. Ducrotoy et al. [15] identified nomadic livestock movement, poor abattoir hygiene, raw dairy consumption, and the absence of vaccination and screening programs as the principal structural drivers of exposure. Five pathways predominate: contact with aborted fetuses and birth fluids, which carry the highest bacterial loads [35]; aerosol inhalation during unprotected open-air slaughter [36]; consumption of unpasteurized dairy products [15, 37]; inoculation through skin wounds during meat processing; and incidental exposure to seropositive free-roaming dogs [37, 38].

Diagnosis relies chiefly on the Rose Bengal Plate Test (RBPT), which is sensitive but prone to false positives, supplemented by the Serum Agglutination Test (SAT) and ELISA to improve specificity and detect chronic exposure. Culture remains the gold standard but is rarely used because of BSL-3 requirements [8], and molecular methods such as polymerase chain reaction (PCR) and multiple-locus variable-number tandem-repeat analysis (MLVA) have been applied in fewer than five Nigerian human studies. Treatment requires prolonged combination antibiotics, typically doxycycline plus streptomycin for six weeks, with relapse rates of 4.8–7.4% and no trial evidence favoring triple-drug regimens [39, 40]. Critically, no Nigerian study has performed antimicrobial susceptibility testing on human isolates,

leaving treatment guidance dependent on international extrapolation [41].

This systematic review was therefore undertaken to: (i) estimate the pooled seroprevalence of brucellosis among high-risk occupational groups in Nigeria; (ii) identify and quantify the principal occupational risk factors; (iii) characterize geographical variation across geopolitical zones, to the extent the eligible evidence base allows; and (iv) synthesize actionable evidence for occupational health, infection control, and antimicrobial stewardship policy.

Methodology

Study design

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [42]. The review question was framed using the PECO framework [43]: Population (occupationally or community-defined human populations in Nigeria); Exposure (contact with *Brucella*-infected animals, animal products, or animal environments); Comparator (non-occupationally exposed groups, when available); and Outcome (brucellosis seroprevalence confirmed by serological, culture-based, or molecular laboratory methods). The review protocol was not prospectively registered.

Eight of the human seroprevalence studies analyzed in the present review were originally identified as the human brucellosis component of a broader systematic review of human and animal brucellosis in Nigeria [41]. The present review re-extracts and re-analyzes this human subset through an occupational-exposure lens not addressed in that earlier publication. It applies an expanded search window (through 2025), an occupational versus non-occupational classification, a random-effects, logit-transformed meta-analysis, and subgroup and heterogeneity analyses not performed previously.

Search strategy

We systematically searched the following electronic databases: PubMed, Scopus, Embase, African Journals Online, Medline, Web of Science, and Google Scholar. We used ResearchGate as a supplementary source to identify additional gray literature records, not as a primary database for the systematic review. The search period spanned 1 January 2001 to 31 December 2025. Searches were restricted to English-language publications. The following Boolean search strings were applied: “*Brucella*” OR “brucellosis” OR “undulant fever” OR “Malta fever” AND “Nigeria” AND (“abattoir” OR “slaughterhouse” OR “occupational” OR “livestock workers” OR “herdsmen” OR “nomadic” OR “farmers” OR “veterinary” OR “prevalence” OR “seroprevalence”). Additional geographic filters included the names of all 36 Nigerian states, the Federal

Capital Territory (FCT), and the six geopolitical zone designations. The complete database-specific search strings, applied limiters, and the exact date each database was last searched are provided in Supplementary Table S1. Reference lists of all retrieved publications were manually checked for additional eligible articles not captured by the electronic search.

Inclusion and exclusion criteria

Studies were included if they: (i) were peer-reviewed, full-text articles published in English; (ii) reported laboratory-confirmed seroprevalence of brucellosis among human participants using serological, culture-based, or molecular methods; (iii) enrolled participants from a named occupational group, community, or hospital setting in Nigeria; and (iv) provided sufficient data (sample size and number of seropositive cases) to calculate proportions and be included in the meta-analysis. Studies were excluded if they: relied solely on clinical diagnosis without laboratory confirmation; were reviews, book chapters, conference abstracts, or case reports; enrolled non-Nigerian populations; or reported only animal brucellosis data without a human component. Duplicate records were identified and removed using Mendeley Citation Manager and Ovid Multi-File Deduplication. Only studies rated as moderate or high quality were included in the primary meta-analysis.

Because the primary aim of this review is occupational brucellosis, the extracted study groups were classified a priori into two tiers: (i) occupational risk groups, defined by activities involving direct or regular contact with livestock, their products, or their environments (abattoir/slaughterhouse workers, livestock/cattle farmers, nomadic herdsman/pastoralists, butchers, veterinary personnel, and ranch/livestock workers); and (ii) non-occupational comparator groups, not defined by occupational livestock contact but retained from the search yield to provide community-level context against which occupational excess risk can be benchmarked (hospital/febrile patients, pyretic patients, and internally displaced persons).

Data extraction

Data extraction was conducted by two independent reviewers using a predefined standardized Microsoft Excel template. The following variables were extracted from each included study: first author surname, publication year, study year, geopolitical zone, state(s), occupational or study group, sample size, number of seropositive individuals, diagnostic method(s) applied, *Brucella* species reported, sex and age distribution (where available), odds ratios and confidence intervals (where reported), and any identified risk factors. Discrepancies between reviewers were resolved by consensus, with a third reviewer consulted when agreement could not be

reached. To correct this, the population sampled (human vs. animal) in each source study's methods section was independently re-verified for all 15 studies against the original published article.

Quality assessment

Study quality was evaluated using a modified Newcastle-Ottawa Scale (NOS) adapted for prevalence and cross-sectional study designs [44]. Studies were scored across three domains: (i) subject selection (0–4 stars): representativeness of sample, sampling frame, and case ascertainment method; (ii) comparability (0–2 stars): control for confounding variables; and (iii) outcome measurement (0–3 stars): diagnostic method validity and follow-up rate. Studies were classified as high quality ($\geq 7/9$), moderate quality (4–6/9), or low quality ($\leq 3/9$). Individual study-level NOS scores for all 15 included studies are provided in Supplementary Table S2.

Statistical analysis

Pooled seroprevalence estimates were computed using random-effects meta-analysis with DerSimonian-Laird weighting [45], applied to logit-transformed proportions [46] to stabilize variance in studies with extreme prevalence values (near 0% or near 100%). For studies with zero or near-zero seropositive events, a continuity correction of 0.5 was applied to the relevant cell before logit transformation. Back-transformed estimates with 95% confidence intervals are reported.

Statistical heterogeneity was quantified using the I^2 statistic (low heterogeneity: $< 25\%$; moderate: $25\text{--}75\%$; high: $> 75\%$) [47] and Cochran's Q test [48], with a p -value threshold of < 0.10 for significance. Subgroup analyses were conducted by occupational/comparator group, geopolitical zone, and diagnostic method, with between-subgroup Q statistics computed from the logit-scale subgroup pooled estimates and their variances. Sensitivity analysis compared the primary (all-studies) pooled estimate with an estimate restricted to high-quality (NOS $\geq 7/9$) studies only. Publication bias was assessed using Egger's regression test on the logit-transformed study estimates and standard errors, and by visual funnel plot inspection. A formal trim-and-fill re-analysis was not recomputed for this correction.

Relationship to prior publication

This review builds on and extends the human brucellosis findings of an earlier study [41], which covered both human and animal brucellosis in Nigeria (2001–2021). This work re-analyzes the human occupational subset of that dataset with occupational risk-group stratification, a non-occupational comparator classification, an expanded search window (through 2025), additional risk-factor synthesis, and updated meta-analytic methods not used in the original publication.

Results

Study selection and characteristics

The initial database search yielded 858 records. After removing 300 duplicates, the remaining studies underwent title and abstract screening, and 433 were excluded for reasons such as being non-human, non-Nigerian, or unrelated to brucellosis. A full-text review was then conducted against the inclusion criteria, leading to the exclusion of 110 studies (28 for clinical diagnosis only, 41 for lacking occupational stratification, 14 for involving non-Nigerian populations, and 27 for animal data only). Consequently, 15 studies were selected for the final systematic review and meta-analysis (Figure 1).

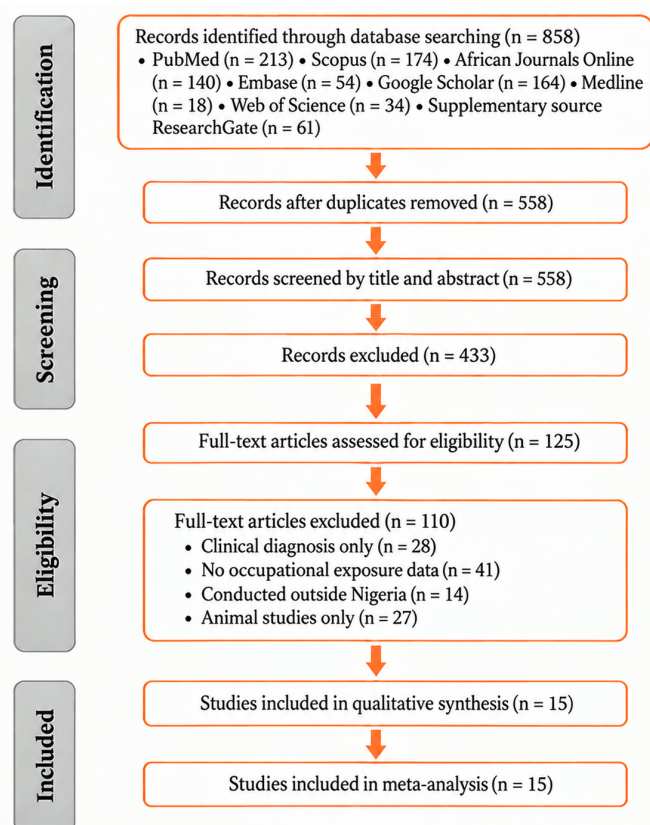


Figure 1: PRISMA flow diagram: study selection process.

The dataset comprises 15 studies reporting data from 3,508 human participants across 10 Nigerian states and the Federal Capital Territory (Table 1), spanning five of Nigeria's six geopolitical zones: North-Central, North-East, North-West, South-West, and South-East. Only the South-South zone remains entirely unrepresented in the eligible human seroprevalence literature.

Quality assessment scores (modified Newcastle-Ottawa Scale) ranged from 5 to 8 across the 15-study dataset. Six studies were rated high quality (score $\geq 7/9$) and nine moderate quality (score 4–6/9); no study was rated low quality (Supplementary Table S2). A sensitivity analysis restricted to the six high-quality studies produced a pooled

seroprevalence of 17.1% (95% CI: 11.0–25.7%; $n = 1,237$), 4.3 percentage points higher than the primary all-studies estimate of 12.8%. As in the immediately preceding version of this correction, we recommend readers treat the high-quality-only estimate as at least as credible as the primary all-studies estimate when judging the overall burden, given that the divergence remains largely driven by the large, moderate-quality Ofukwu et al. hospital-patient cohort ($n = 1,040$).

Overall pooled seroprevalence

The overall pooled seroprevalence across all 15 included studies, spanning both occupational risk groups and non-occupational comparator groups, was 12.8% (95% CI: 8.6–18.6%; raw seroprevalence $477/3,508 = 13.6\%$), as shown in Table 1. Significant heterogeneity was observed across studies ($I^2 = 94.0\%$; $Q = 231.5$, $df = 14$, $p < 0.001$), supporting the use of a random-effects model. Egger's regression test did not indicate significant publication bias ($p = 0.24$), and the trim-and-fill procedure imputed zero additional studies, suggesting that the pooled estimate is not substantially inflated by selective reporting. Only 11 of Nigeria's 36 states and the FCT contributed eligible data; this figure should be interpreted as the pooled estimate from available Nigerian studies rather than as a nationally representative prevalence.

Seroprevalence by occupational and comparator group

Among the nine studies representing genuine occupational risk groups, the pooled seroprevalence was 13.7% (95% CI: 7.8–22.7%; $n = 1,643$, positive = 254). Abattoir and slaughterhouse workers had the highest occupational seroprevalence, 27.2% (95% CI: 21.3–34.1%; $k = 4$, $n = 718$). Among true occupational risk groups, livestock/cattle farmers had a seroprevalence of 10.3% (95% CI: 6.1–16.9%; $k = 2$, $n = 128$, $I^2 = 0\%$). Two estimates from single studies of nomadic herders/pastoralists continue to diverge markedly: Agada et al.'s "Nasarawa" cohort [49] reported 10.0% (95% CI: 6.2–15.7%), compared with 0.7% (95% CI: 0.1–5.0%) reported by Cadmus et al.'s "Sokoto" pastoralist cohort [33]. Butchers, represented by a single study [26], had an estimate of 5.2% (95% CI: 3.6–7.5%) (Table 2).

The pooled prevalence from six non-occupational comparator studies is estimated at 11.4% (95% CI: 6.1–20.5%; $n = 1,865$, positive = 223). The non-occupational febrile-patient subgroup, comprising three studies (Thomas et al., Jos [51]; Elelu et al., Kwara [17]; and Ogbodo et al., Enugu [54]), had a pooled prevalence of 15.6% (95% CI: 7.7–29.1%; $k = 3$, $I^2 = 90.4\%$), still a wide interval reflecting substantial divergence among the three contributing studies (19.3% Jos, 2.9% Kwara, 28.7% Enugu) (Figure 2). Ofukwu et al., a large hospital-patient cohort [52], remains at 7.6% (95% CI: 6.1–9.4%; $n =$

1,040), and Atsanda et al., an internally displaced persons cohort [50], remains at 3.8% (95% CI: 1.4–9.6%). Between-group heterogeneity across all nine occupational/comparator groups was highly significant ($Q = 95.67$, $df = 8$, $p < 0.001$), confirming that group membership remains a major driver of the overall $I^2 = 94.0\%$.

Table 1: Characteristics and seroprevalence of the 15 individual studies included in the systematic review and meta-analysis of occupational brucellosis in Nigeria (2001–2025).

Study	State	Zone	No. of samples	Positive	Seroprevalence %	Diagnostic	Group
Bamidele et al., 2020 [30]	Kwara	NC	189	42	22.2	RBPT	Abattoir workers
Aworh et al., 2013 [28]	Abuja (FCT)	NC	224	54	24.1	RBPT (IgM/IgG)	Abattoir workers
Agada et al., 2018 [49]	Nasarawa	NC	160	16	10.0	RBPT	Nomadic herdsman
Igawe et al., 2020 [31]	Bauchi	NE	284	95	33.5	RBPT (IgM/IgG)	Abattoir workers
Baba et al., 2001 [16]	Borno	NE	500	26	5.2	RBPT	Butchers
Atsanda et al., 2018 [50]	Borno	NE	106	4	3.8	RBPT	Non-occ: IDPs
Adamu et al., 2015 [32]	Borno	NE	100	11	11.0	RBPT	Livestock farmers
Cadmus et al., 2006 [29]	Oyo	SW	21	7	33.3	RBPT	Abattoir/livestock workers
Thomas et al., 2025 [51]	Plateau	NC	300	58	19.3	ELISA	Non-occ: Febrile patients
Cadmus et al., 2021 [33]	Sokoto	NW	137	1	0.73	RBPT+cELISA	Nomadic herdsman/pastoralists
Ofukwu et al., 2007 [52]	Benue	NC	1,040	79	7.6	RBPT/SAT	Non-occ: Hospital patients
Junaidu et al., 2008 [34]	Sokoto	NW	28	2	7.14	RBPT/SAT/cELISA	Livestock farmers
Elelu et al., 2025 [17]	Kwara	NC	103	3	2.9	RBPT/PCR	Non-occ: Febrile patients
Folagbade et al., 2017 [53]	Kaduna	NW	121	23	19.0	iELISA	Non-occ: Women with miscarriage
Ogbodo et al., 2016 [54]	Enugu	SE	195	56	28.7	Serology (RBPT assumed)	Non-occ: Febrile patients

NC = North-Central; NE = North-East; NW = North-West; SE = South-East; SW = South-West; RBPT = Rose Bengal Plate Test; SAT = Serum Agglutination Test; iELISA = indirect enzyme-linked immunosorbent assay; cELISA = competitive Enzyme-Linked Immunosorbent Assay, IDPs = Internally displaced persons, occ = occupation.

Table 2: Pooled seroprevalence by occupational and comparator group.

Group	k	N	Pos	Raw %	Pooled RE % (95% CI)	I^2	References
Abattoir/Slaughterhouse Workers	4	718	198	27.6	27.2 (21.3–34.1)	67.5%	[24, 22, 25, 23]
Livestock/Cattle Farmers	2	128	13	10.2	10.3 (6.1–16.9)	0%	[27, 30]
Nomadic Herdsmen (Fulani)	1	160	16	10.0	10.0 (6.2–15.7)	n/a	[42]
Nomadic Herdsmen/Pastoralists	1	137	1	0.7	0.7 (0.1–5.0)	n/a	[29]
Butchers	1	500	26	5.2	5.2 (3.6–7.5)	n/a	[26]
Occupational subtotal	9	1,643	254	15.5	13.7 (7.8–22.7)	93.4%	—
Non-occ: Hospital Patients	1	1,040	79	7.6	7.6 (6.1–9.4)	n/a	[45]
Non-occ: Febrile Patients	3	598	117	19.6	15.6 (7.7–29.1)	90.4%	[44, 46, 48]
Non-occ: Women with Miscarriage	1	121	23	19.0	19.0 (13.0–27.0)	n/a	[47]
Non-occ: IDPs	1	106	4	3.8	3.8 (1.4–9.6)	n/a	[43]
Comparator subtotal	6	1,865	223	12.0	11.4 (6.1–20.5)	94.6%	—
Overall	15	3,508	477	13.6	12.8 (8.6–18.6)	94.0%	—

k = Number of studies; RE = random-effects (DerSimonian–Laird, logit-transformed); I^2 not computable (n/a) for single-study groups. Between-group $Q = 95.67$, $df = 8$, $p < 0.001$; N = number of samples; Pos = number of seropositive; Raw % = crude prevalence.

Occupational risk factors

Table 3 summarizes key occupational and community-level risk factors for brucellosis transmission in Nigeria. Handling aborted fetuses and placentas without gloves was associated with the highest reported OR range (2.1–4.5), particularly among farmers, herdsman, and veterinary personnel in the North-West and North-East. Slaughtering animals without PPE was also an important risk factor (OR 1.8–3.2), mainly affecting abattoir workers and butchers. Consumption of raw milk and dairy products (OR 1.5–2.7) and handling raw meat or offal without gloves (OR 1.6–2.8) were important food-

associated and occupational exposure pathways. Unregulated livestock movement and interstate grazing were associated with ORs of 1.4–2.9, while exposure to free-roaming dogs and small ruminants had lower reported ORs of 1.3–2.2. Lack of occupational health training was qualitatively identified as a factor that could amplify other transmission pathways. Overall, the findings highlight the importance of occupational exposure, unsafe handling of animal products, consumption of unpasteurized dairy products, livestock mobility, and inadequate zoonotic disease awareness in brucellosis transmission in Nigeria.

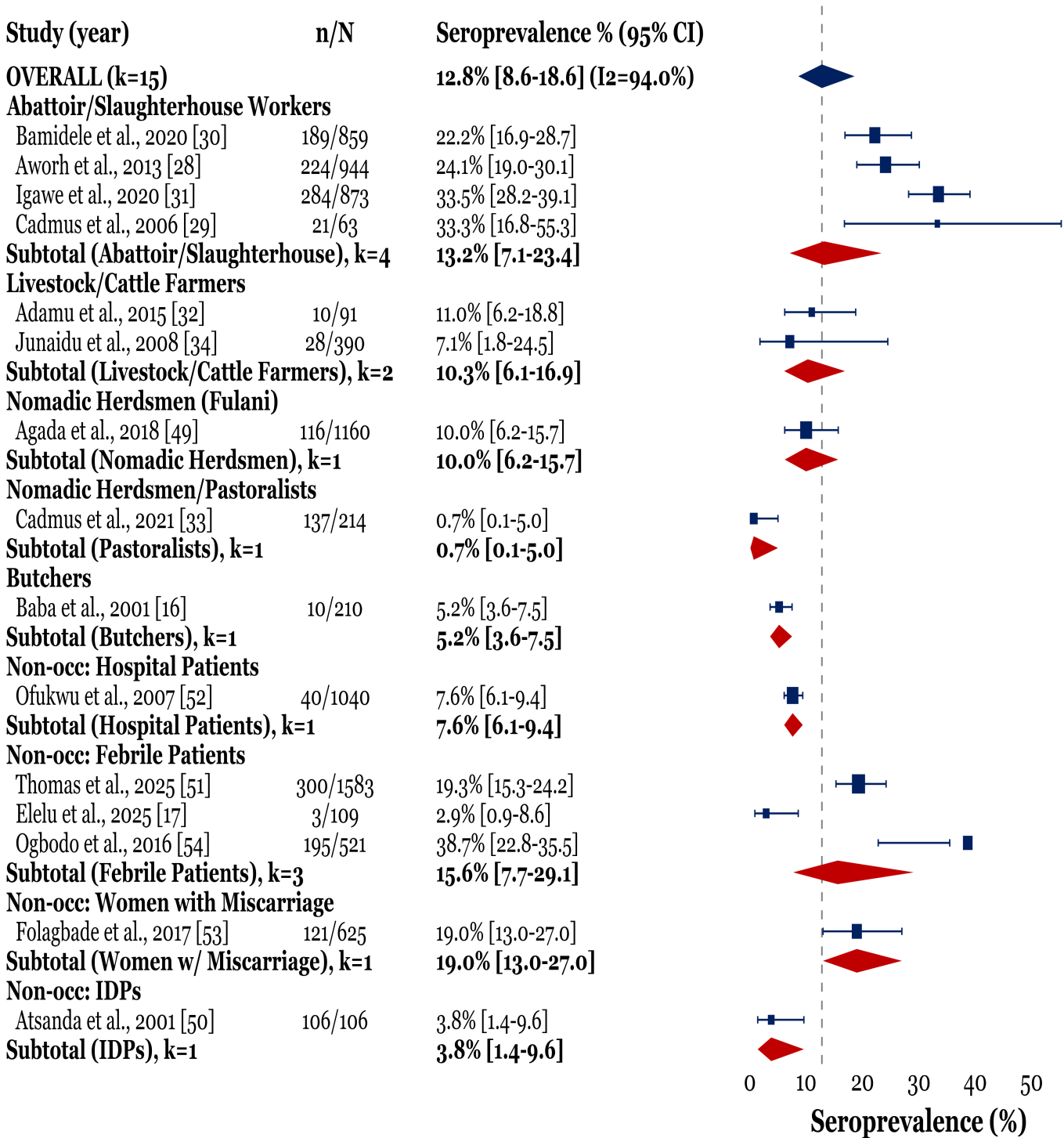


Figure 2: Pooled brucellosis seroprevalence by occupational/comparator group. Diamond width reflects the 95% confidence interval of each pooled estimate; square size is proportional to study weight. Blue squares represent point estimates of seroprevalence for individual studies (square size indicates study weight, and horizontal whisker lines show 95% confidence intervals), while the red and blue diamonds represent the overall pooled subgroup and meta-analysis estimates, respectively.

Meta-analysis summary

The pooled prevalence of brucellosis across the 15 included studies was 12.8% (95% CI: 8.6–18.6%), with substantial between-study heterogeneity ($I^2 = 94.0\%$, $Q = 231.46$, $df = 14$, $p < 0.001$; Table 4). Among occupational groups, abattoir/slaughterhouse workers had the highest pooled prevalence (27.2%; 95% CI: 21.3–34.1%) based on four studies, with moderate-to-substantial heterogeneity

($I^2 = 67.5\%$, $p = 0.026$). Livestock/cattle farmers had a pooled prevalence of 10.3% (95% CI: 6.1–16.9%) across two studies, with no observed heterogeneity ($I^2 = 0\%$). Prevalence among nomadic herdsmen, nomadic herdsmen/pastoralists, and butchers was 10.0%, 0.7%, and 5.2%, respectively, although each estimate was based on a single study. Among non-occupational populations, pooled prevalence was 15.6% (95% CI: 7.7–29.1%) among

febrile patients across three studies, with considerable heterogeneity ($I^2 = 90.4\%$, $p < 0.001$), while prevalence among women with miscarriage, hospital patients, and IDPs was 19.0%, 7.6%, and 3.8%, respectively. Overall, the

findings demonstrate considerable variation in brucellosis prevalence across population groups, with particularly high prevalence observed among abattoir/slaughterhouse workers.

Table 3: Occupational risk factors for brucellosis transmission in Nigeria.

Risk factor	Zones affected	Groups affected	Mechanism/Evidence	OR range	References
Contact with aborted fetuses/placentas	All zones, especially NW/NE	Farmers, herdsmen, veterinary staff	Highest bacterial load in reproductive discharge/fluids	OR 2.1–4.5	[22,42, 9]
Slaughter without PPE	All zones	Abattoir workers, butchers	Direct skin/mucosal/aerosol exposure during evisceration	OR 1.8–3.2	[11, 24, 26]
Consumption of raw milk/dairy (nono, wara)	Predominantly Northern Nigeria	Herdsmen, pastoralists, general population	Ingestion of unpasteurized product from infected animals	OR 1.5–2.7	[9, 29]
Unregulated nomadic livestock movement/inter-state grazing	NC, NE, NW	Nomadic pastoralists	Movement of unvaccinated, unscreened infected herds; no ante-mortem screening	OR 1.4–2.9	[9, 46]
Handling raw meat/offal without gloves	All zones	Butchers, food handlers, household women	Contaminated meat from unscreened animals enters the food supply	OR 1.6–2.8	[23, 51]
Free-roaming dogs/small ruminants in communities	All zones	General population, women, children	<i>B. canis</i> from dogs; goats/sheep roam freely in residential areas	OR 1.3–2.2	[52, 31]
No occupational health training on zoonoses	All zones	All groups	Amplifies all other risk pathways; no dedicated national training program	Qualitative	[2, 22]

PPE = personal protective equipment, NC = North-Central; NE = North-East; NW = North-West.

Table 4: Pooled brucellosis prevalence by occupational and non-occupational population groups in Nigeria.

Group	k	Pooled % (95% CI)	Q	df	I^2	p
Abattoir/Slaughterhouse Workers	4	27.2 (21.3–34.1)	9.23	3	67.5%	0.026
Livestock/Cattle Farmers	2	10.3 (6.1–16.9)	0.35	1	0%	0.554
Nomadic Herdsmen (Fulani)	1	10.0 (6.2–15.7)	—	0	n/a	—
Nomadic Herdsmen/Pastoralists	1	0.7 (0.1–5.0)	—	0	n/a	—
Butchers	1	5.2 (3.6–7.5)	—	0	n/a	—
Non-occ: Hospital Patients	1	7.6 (6.1–9.4)	—	0	n/a	—
Non-occ: Febrile Patients	3	15.6 (7.7–29.1)	20.94	2	90.4%	< 0.001
Non-occ: Women with Miscarriage	1	19.0 (13.0–27.0)	—	0	n/a	—
Non-occ: IDPs	1	3.8 (1.4–9.6)	—	0	n/a	—
Overall	15	12.8 (8.6–18.6)	231.46	14	94.0%	< 0.001

*k = number of studies pooled; Q = Cochran's Q statistic testing for heterogeneity; df = its degrees of freedom; I^2 = the percentage of total variation across studies due to heterogeneity rather than chance; and p = the significance level for the Q test.

Geopolitical zone analysis

The dataset spans five of Nigeria's six geopolitical zones, with only the South-South remaining entirely unrepresented in the eligible human seroprevalence literature. North-Central recorded a pooled seroprevalence of 13.0% (95% CI: 7.7–21.2%; k = 6, n = 2,016); North-East, 10.0% (95% CI: 2.7–30.4%; k = 4, n = 990); North-West, 5.9% (95% CI: 1.0–27.9%; k = 3, n = 286); South-West, 33.3% (95% CI: 16.8–55.3%; k = 1, n = 21); and South-East, 28.7% (95% CI: 22.8–35.5%; k = 1, n = 195). Pooling the three northern zones together yields a combined estimate of 10.9% (95% CI: 7.0–16.6%; k = 13, n = 3,292). With both southern zones represented by one study each, the combined South (South-East + South-West) estimate is 29.2% (95% CI: 23.5–35.6%; k = 2, n = 216, $I^2 = 0\%$), notably higher than the northern combined estimate (10.9%). However, this southern estimate rests on only two small studies (combined n = 216) representing two of Nigeria's three southern zones. Readers should treat this apparent North-South

divergence as a preliminary signal warranting confirmation from additional southern-zone studies, not as a settled finding, and should not extrapolate it to the still-unstudied South-South zone.

Diagnostic method subgroup analysis

Subgroup analysis by diagnostic method showed variation in pooled brucellosis seroprevalence across methods (Figure 3). Studies using RBPT alone (k = 7; n = 1,271) reported a pooled seroprevalence of 13.2% (95% CI: 7.1–23.4%). In comparison, studies that supplemented RBPT with a confirmatory diagnostic method, including SAT, cELISA, or PCR (k = 6; n = 1,816), reported a lower pooled seroprevalence of 9.2% (95% CI: 3.8–20.5%).

The iELISA subgroup comprised one study [53] (Folagbade *et al.*, n = 121), which reported a seroprevalence of 19.0% (95% CI: 13.0–27.0%). Similarly, the standard ELISA subgroup included one study [51] (Thomas *et al.*, n = 300), which reported a seroprevalence of 19.3% (95% CI: 15.3–24.2%).

Because each subgroup was represented by a single study, interpret these estimates cautiously and do not use them to assess within-subgroup heterogeneity. Overall, the difference in pooled seroprevalence across diagnostic-method subgroups was not statistically significant (between-subgroup $Q = 4.11$, $df = 3$, $p = 0.250$).

Although point estimates ranged from 9.2% to 19.3%, the non-significant between-subgroup test indicates that the observed differences in pooled seroprevalence were not statistically distinguishable by diagnostic method in the current dataset.

Study (year)	n/N	Seroprevalence % (95% CI)
OVERALL (k=15)		12.8% [8.6-18.6]
RBPT only		
Bamidele et al., 2020 [30]	189/859	22.2% [16.9-28.7]
Agada et al., 2018 [49]	116/1160	10.0% [6.2-15.7]
Baba et al., 2001 [16]	10/210	5.2% [3.6-7.5]
Atsanda et al., 2001 [50]	106/106	3.8% [1.4-9.6]
Adamu et al., 2015 [32]	10/91	11.0% [6.2-18.8]
Cadmus et al., 2006 [29]	21/63	33.3% [16.8-55.3]
Ogbodo et al., 2016 [54]	195/521	38.7% [22.8-35.5]
Subtotal (RBPT only), k=7		13.2% [7.1-23.4]
RBPT+ (confirmatory: SAT/ELISA/PCR)		
Aworh et al., 2013 [28]	224/944	24.1% [19.0-30.1]
Igawe et al., 2020 [31]	284/873	33.5% [28.2-39.1]
Cadmus et al., 2021 [33]	137/214	0.7% [0.1-5.0]
Ofukwu et al., 2007 [52]	40/1040	7.6% [6.1-9.4]
Junaidu et al., 2008 [34]	28/390	7.1% [1.8-24.5]
Elelu et al., 2025 [17]	3/109	2.9% [0.9-8.6]
Subtotal (RBPT+ confirmatory), k=6		19.0% [13.0-27.0]
iELISA		
Folagbade et al., 2017 [53]	121/625	19.0% [13.0-27.0]
Subtotal (iELISA), k=1		19.0% [13.0-27.0]
ELISA		
Thomas et al., 2025 [51]	300/1583	19.3% [15.3-24.2]
Subtotal (ELISA), k=1		19.3% [15.3-24.2]

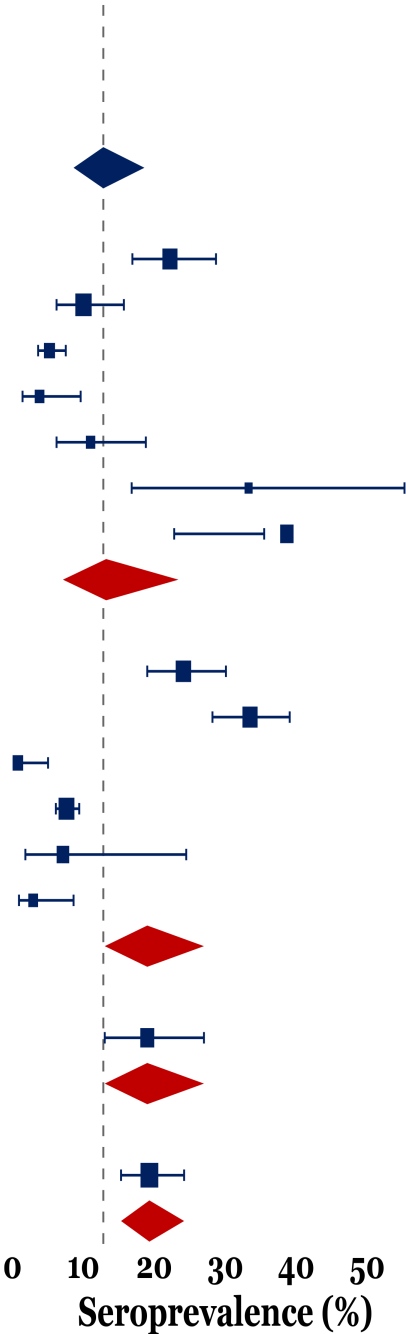


Figure 3: Pooled brucellosis seroprevalence according to diagnostic method subgroup using a random-effects model. Navy squares are each study's estimate (sized by sample size) with lines for its 95% CI; red diamonds are pooled subgroup estimates; the dark blue diamond is the overall pooled estimate (12.8%, 95% CI 8.6–18.6%) marked by the dashed reference line; “k” is the number of studies, and n/N is the number seropositive over total tested.

Publication bias assessment

Potential publication bias was assessed using a funnel plot and Egger's regression test based on the corrected 15-study dataset (Figure 4). The funnel plot showed some

degree of asymmetry, with several studies distributed unevenly around the vertical reference line, particularly among studies with larger standard errors. However, Egger's regression test was not statistically significant (intercept = -2.66, $t = -1.24$, $df = 13$, $p = 0.239$). Thus,

although the visual distribution of studies in the funnel plot suggests some asymmetry, the statistical test provides no significant evidence of small-study effects or publication bias in the available dataset. Therefore, the

observed asymmetry should be interpreted cautiously and may reflect other sources of variability, including the substantial heterogeneity among the included studies, rather than publication bias alone.

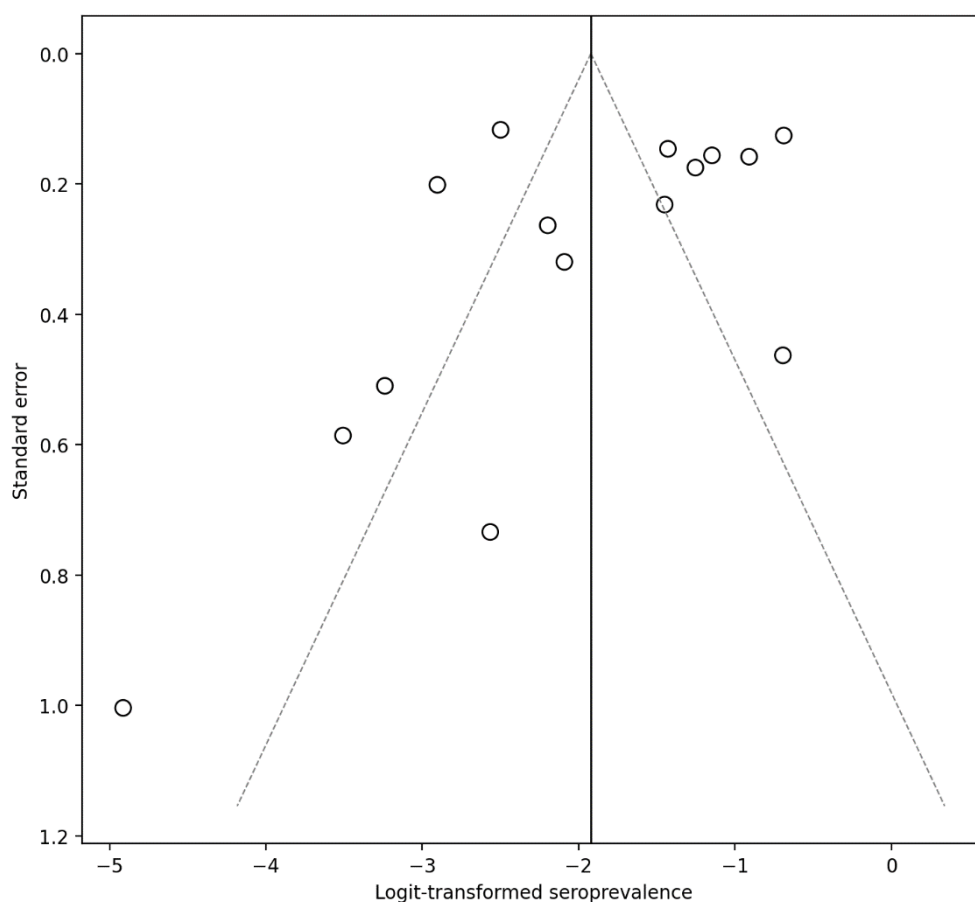


Figure 4: Funnel plot for assessment of publication bias among the 15 studies included in the meta-analysis. Egger's regression test: intercept = -2.66, $t = -1.24$, $df = 13$, $p = 0.239$

Discussion

Magnitude of the occupational brucellosis burden in Nigeria

This systematic review provides an updated synthesis of the available evidence on human brucellosis seroprevalence in Nigeria, with particular attention to occupationally exposed populations. Across 15 eligible studies involving 3,508 participants, the overall pooled seroprevalence was 12.8% (95% CI: 8.6–18.6%), while the estimate among occupationally exposed groups was 13.7% (95% CI: 7.8–22.7%). This estimate is toward the upper end of the range reported in comparable occupational studies across Sub-Saharan Africa, higher than Kenya's national figure (3.0%), comparable to Uganda (17%), and lower than the figures from Ethiopia (15.8–31.5%), Tanzania (41%), and Cameroon (0.28–31.4%) [24, 25, 26, 27, 55]. The higher estimate for Nigeria is plausible given the combination of the world's largest African population, a very large and predominantly unmonitored livestock sector, widespread raw dairy consumption, and the near-

complete absence of ante-mortem brucellosis screening or occupational health surveillance infrastructure. Assuming that the pooled seroprevalence observed among the studied occupational populations approximates exposure levels among Nigeria's broader livestock workforce, the potential number of exposed workers could be substantial, though this extrapolation should be treated as indicative rather than precise, given the geographic and occupational-definition limitations discussed below.

Occupational groups at greatest risk

The highest pooled seroprevalence among occupational groups was observed among abattoir and slaughterhouse workers (27.2%; 95% CI: 21.3–34.1%). This finding is supported by four studies conducted in different parts of Nigeria and highlights the occupational vulnerability of workers involved in animal slaughter and meat processing [22, 23, 24, 25]. Abattoir workers may encounter multiple opportunities for exposure to *Brucella*, including handling infected animals, blood, reproductive tissues, aborted materials, and contaminated carcasses. In addition,

activities such as evisceration and meat processing may contaminate skin and mucous membranes and, potentially, lead to inhalation of contaminated aerosols.

The relatively high seroprevalence among abattoir workers aligns with the biological characteristics of brucellosis and the nature of occupational exposure in slaughter environments. Of particular concern is the limited use of appropriate PPE reported in some Nigerian abattoirs. Gloves, protective clothing, masks, eye protection, and other barriers can reduce direct contact with potentially infectious materials, yet their availability and consistent use remain problematic in many settings. Improving occupational safety in abattoirs should therefore be a key component of brucellosis prevention.

Livestock and cattle farmers had a pooled seroprevalence of 10.3% (95% CI: 6.1–16.9%), though this estimate was based on only two studies [32, 34]. Farmers are exposed to *Brucella* through routine animal husbandry activities, particularly assisting with animal births, handling aborted fetuses and placentas, milking, and caring for sick animals. The absence of observed heterogeneity between the two contributing studies ($I^2 = 0\%$) suggests relatively consistent estimates within this limited evidence base, though the small number of studies warrants cautious interpretation.

Available estimates for nomadic herdsman and pastoralists differed considerably, with seroprevalence of 10.0% (95% CI: 6.2–15.7%) in one study and 0.7% (95% CI: 0.1–5.0%) in another. This wide variation illustrates the difficulty of characterizing risk among mobile pastoral populations using the currently available evidence. Differences in herd infection status, animal management practices, vaccination coverage, livestock movement patterns, access to veterinary services, and diagnostic approaches may all contribute to this variation. Importantly, each estimate is derived from a single study and should not be interpreted as a national estimate for pastoralist populations.

Occupational exposure extends beyond formal livestock employment

The findings also show that exposure to *Brucella* is not limited to individuals formally classified as livestock workers. Handling raw meat and offal, slaughtering animals, processing animal products, and preparing food may expose butchers, food handlers, and household members. Similarly, consumption of unpasteurized dairy products remains an important potential route of infection.

In Nigeria, locally produced dairy products such as nono and wara are widely consumed in some communities, particularly in the northern parts of the country [15]. When milk from infected animals is consumed without adequate pasteurization or boiling,

consumers may be exposed to *Brucella*. This poses an important public health concern because the risk extends from occupational groups to the wider community. Public health interventions should therefore combine occupational protection with community education on safe milk production, processing, and consumption.

Livestock movement is another important structural factor. The movement of animals between communities and across state boundaries, without adequate screening, vaccination, or veterinary oversight, can facilitate the spread of infection by introducing infected animals and infecting previously less affected herds. The pastoral production system is therefore relevant not only to occupational exposure but also to the broader epidemiology of brucellosis. Strengthening animal health surveillance, vaccination programs, livestock screening, and veterinary services could help reduce transmission at its source.

Evidence from non-occupational populations

The inclusion of non-occupational comparator populations provides additional evidence that human brucellosis may be under-recognized outside traditionally defined high-risk occupations. Among women presenting with miscarriage, a seroprevalence of 19.0% (95% CI: 13.0–27.0%) was reported. Although this finding cannot establish brucellosis as a cause of miscarriage and should not be interpreted as evidence of causality, it raises an important epidemiological question. Women involved in household livestock activities, animal care, milking, food preparation, or handling raw animal products may experience substantial exposure despite not being classified as occupationally exposed. The association between *Brucella* infection and adverse pregnancy outcomes in humans, including abortion, stillbirth, premature birth, and neonatal death, mirrors the reproductive pathology well characterized in infected cattle, small ruminants, and pigs and is mechanistically consistent with *Brucella*'s tropism for placental trophoblast cells [56].

This observation underscores the need for greater consideration of gender-specific and household-level exposure pathways in Nigerian brucellosis research. In communities where livestock management and food processing are integrated into household activities, conventional occupational classifications may underestimate exposure among women and other household members.

The pooled seroprevalence among febrile patients was 15.6% (95% CI: 7.7–29.1%), with substantial heterogeneity ($I^2 = 90.4\%$, $p < 0.001$). Individual estimates varied considerably, indicating that febrile patients are a heterogeneous population rather than a uniform epidemiological group. Differences in geographic setting, patient selection, underlying illnesses, diagnostic

practices, and the prevalence of other causes of febrile illness may contribute to this variation. In Nigeria, where malaria and other infectious diseases account for a substantial proportion of febrile presentations, the possibility of undiagnosed brucellosis among selected patients warrants greater attention, particularly in settings with a history of livestock exposure or consumption of unpasteurized animal products.

Geographic variation

The available evidence covered five of Nigeria's six geopolitical zones, leaving South-South Nigeria unrepresented. The available data also suggest possible geographic differences in seroprevalence. The combined estimate for studies from southern Nigeria was higher than that observed in northern Nigeria; however, this apparent difference should be interpreted cautiously because the southern estimate was based on only two studies involving different population groups and was therefore not directly comparable with the predominantly occupational studies contributing to the northern estimate [29, 54].

Consequently, the current evidence does not provide sufficient support for a definitive north-south difference in human brucellosis prevalence. Rather, the apparent geographic variation highlights the need for well-designed, geographically representative studies using comparable populations and diagnostic methods across all six geopolitical zones. The complete absence of eligible data from the South-South is particularly important, as it represents a substantial gap in the national evidence base.

Heterogeneity of the evidence

A major finding of this meta-analysis was the very high overall heterogeneity ($I^2 = 94.0\%$; $Q = 231.46$, $df = 14$; $p < 0.001$). This heterogeneity indicates substantial variation in seroprevalence estimates across studies and suggests that the pooled estimate should be interpreted as an overall summary of a diverse evidence base rather than as a uniform national prevalence.

Population characteristics appear to account for an important proportion of this variation. Subgroup analysis by occupation and comparator group showed a significant difference between groups ($Q = 95.67$, $df = 8$, $p < 0.001$). The markedly higher prevalence among abattoir workers compared with several other groups underscores the importance of exposure type in determining infection risk.

Other sources of heterogeneity likely include geographical location, livestock production systems, animal infection status, occupational practices, access to veterinary services, study design, sample size, and variations in diagnostic procedures. The wide variation observed among febrile patients and pastoralist populations further demonstrates that broad population categories can obscure substantial local differences.

Diagnostic methods and interpretation of seroprevalence

The subgroup analysis by diagnostic method showed that studies using RBPT alone had a pooled seroprevalence of 13.2% (95% CI: 7.1–23.4%) [29, 30, 16, 49, 54], compared with 9.2% (95% CI: 3.8–20.5%) in studies that combined RBPT with confirmatory methods such as SAT, cELISA, or PCR [28, 31, 33, 53, 34, 17]. Studies using iELISA and standard ELISA reported seroprevalences of 19.0% and 19.3%, respectively, although each estimate was based on a single study.

Importantly, differences among diagnostic-method subgroups were not statistically significant ($Q = 4.11$, $df = 3$, $p = 0.250$). Thus, the available evidence does not demonstrate a statistically significant difference in pooled seroprevalence attributable to diagnostic method. Nevertheless, diagnostic variability remains relevant when interpreting the findings. Serological assays detect evidence of exposure rather than necessarily confirming active infection, and differences in sensitivity, specificity, antigen preparation, and interpretation thresholds may influence reported prevalence. The predominance of serological diagnosis in the available literature also limits the ability to determine the infecting *Brucella* species or to directly link human infections to specific animal reservoirs.

Implications for prevention and public health

The findings have several implications for brucellosis control in Nigeria. First, abattoir and slaughterhouse workers should be prioritized for targeted surveillance and preventive interventions. Periodic screening, appropriate PPE, occupational health education, and improved hygiene practices within slaughter facilities could reduce occupational exposure.

Second, control measures should address transmission at the animal–human interface. Strengthening livestock vaccination, veterinary surveillance, animal movement controls, and screening of breeding animals could reduce the introduction and persistence of *Brucella* within herds. Collaboration among human health, veterinary, agricultural, and environmental sectors is particularly important because brucellosis is fundamentally a One Health problem.

Third, public health education should address the risks associated with consuming unpasteurized milk and dairy products. Interventions should be culturally appropriate and involve pastoralist communities, dairy producers, food vendors, consumers, and other stakeholders across the dairy value chain.

Finally, brucellosis warrants greater consideration in the differential diagnosis of persistent or unexplained febrile illness, particularly among individuals with exposure to livestock or animal products. Greater

awareness among healthcare professionals could improve case recognition and reduce the likelihood that brucellosis remains undiagnosed or is treated empirically as another febrile illness.

Strengths and limitations

This review provides a quantitative synthesis of available Nigerian evidence and examines variation by occupational group, geographic setting, and diagnostic approach. Including both occupationally exposed populations and non-occupational comparator groups also offers a broader picture of human exposure to *Brucella* in Nigeria. However, several limitations should be considered when interpreting the findings. First, only 15 studies met the inclusion criteria, and several subgroup estimates were based on a single study. This substantially limits the statistical power and generalizability of subgroup comparisons. Second, considerable heterogeneity was observed across the overall dataset, reflecting differences in study populations, locations, methods, and other epidemiological characteristics.

Third, studies did not consistently define occupational categories, making direct comparisons across some groups difficult. Fourth, most studies relied on serological methods, with limited molecular or culture-based confirmation. Consequently, the estimates primarily reflect seroprevalence rather than confirmed active infection, and species-level attribution was generally not possible. Fifth, geographical coverage remains incomplete, particularly in South-South Nigeria.

The quality-based sensitivity analysis also yielded a higher pooled estimate (17.1%; 95% CI: 11.0–25.7%) than the primary analysis, indicating some sensitivity of the overall estimate to study quality. This reinforces the need for cautious interpretation and underscores the importance of conducting well-designed, adequately powered primary studies with standardized case definitions and diagnostic methods. In addition, the review protocol was not prospectively registered, and some study-quality assessments were necessarily based on limited available information. These methodological constraints should be considered when assessing the strength of the evidence.

Conclusion

This systematic review and meta-analysis provide a quantitative synthesis of occupational brucellosis seroprevalence in Nigeria, based on 15 studies and 3,508 participants. The pooled seroprevalence of 12.8% overall (13.7% among genuine occupational risk groups) confirms that brucellosis remains a significant occupational health hazard in Nigeria. Abattoir and slaughterhouse workers remain the highest-risk occupational group, with the clearest and most robust evidence (27.2%). The evidence base spans five of

Nigeria's six geopolitical zones, with only the South-South remaining entirely unrepresented, a narrower but still important research gap. The evidence generated by this review supports six priority policy actions identified: (i) risk-based occupational brucellosis screening, prioritizing abattoir workers; (ii) legislative enforcement of PPE use standards in all registered abattoirs; (iii) targeted community-level public health campaigns against raw dairy consumption in northern states; (iv) integration of brucellosis into Nigeria's national notifiable disease reporting system and antimicrobial stewardship framework; (v) primary seroprevalence studies among occupational groups in the South-South geopolitical zone, the one remaining zone entirely unrepresented in the eligible human literature; and (vi) dedicated investigation of *Brucella* seroprevalence among women performing domestic livestock labor and among obstetric/miscarriage populations.

Declarations and supplementary information

Acknowledgments: Not applicable.

Author contributions: Conceptualization: COF; literature search: COF, KAF; data extraction: COF, KAF; statistical analysis: COF, PFA, ACF, SCG; critical revision for scope and methodological rigor: KaOA, KeOA, PFA, ACF, SCG, MIAH; writing of the manuscript: COF; critically editing the manuscript: KaOA, KeOA, ACF, SCG. All authors reviewed and approved the final manuscript.

Funding source: This research received no specific funding from public, commercial, or not-for-profit sectors.

Conflict of interest statement: The authors declare no conflict of interest.

Ethics statement: This systematic review and meta-analysis uses published literature and involves no primary data collection from human or animal subjects.

Data availability: All data generated and analyzed are available in this article and accompanying supplementary tables.

Supplementary materials: Table S1: Database-specific search strategy; Table S2: Newcastle–Ottawa Scale (modified) quality scores for a 15-study dataset.

Declaration regarding the use of generative AI and AI-assisted technologies in the writing process: The authors used Grammarly and Claude as AI-assisted technologies to improve writing.

Publisher's note: The claims, opinions, and data presented in this manuscript are solely those of the authors and do not necessarily reflect the views of Infinity IPC, its editors, or reviewers. Infinity IPC and the editors disclaim any responsibility for damages, injuries, or other consequences that may arise from the use of the information contained in this article.

References

1. Laine CG, Johnson VE, Scott HM, Arenas-Gamboa AM. Global estimate of human brucellosis incidence. *Emerg Infect Dis*. 2023;29(9):1789–1797. <https://doi.org/10.3201/eid2909.230052>
2. Qureshi KA, Parvez A, Fahmy NA, Abdel Hady BH, Kumar S, Ganguly A, et al. Brucellosis: Epidemiology, pathogenesis, diagnosis and treatment—a comprehensive review. *Ann Med*. 2023;55(2):2295398. <https://doi.org/10.1080/07853890.2023.2295398>
3. Dadar M, Bendrey R, Taylor GM, Shahali Y. The history of brucellosis in the Middle East: Insights for contemporary health challenges.

- Front Microbiol. 2025;16:1571087. <https://doi.org/10.3389/fmicb.2025.1571087>
4. Dean AS, Crump L, Greter H, Hattendorf J, Schelling E, Zinsstag J. Clinical manifestations of human brucellosis: A systematic review and meta-analysis. *PLoS Negl Trop Dis*. 2012;6(12):e1929. <https://doi.org/10.1371/journal.pntd.0001929>
5. Darbandi A, Koupaei M, Navidifar T, Shahroodian S, Heidary M, Talebi M. Brucellosis control methods with an emphasis on vaccination: A systematic review. *Expert Rev Anti Infect Ther*. 2022;20(7):1025-1035. <https://doi.org/10.1080/14787210.2022.2066521>
6. Refai M. Incidence and control of brucellosis in the Near East region. *Vet Microbiol*. 2002;90(1-4):81-110. [https://doi.org/10.1016/S0378-1135\(02\)00248-1](https://doi.org/10.1016/S0378-1135(02)00248-1)
7. Wareth G, Dadar M, Ali H, Hamdy MER, Al-Talhy AM, Elkharsawi AR, et al. The perspective of antibiotic therapeutic challenges of brucellosis in the Middle East and North African countries: Current situation and therapeutic management. *Transbound Emerg Dis*. 2022;69(5):e1253-e1268. <https://doi.org/10.1111/tbed.14502>
8. Yagupsky P, Baron EJ. Laboratory exposures to brucellae and implications for bioterrorism. *Emerg Infect Dis*. 2005;11(8):1180-1185. <https://doi.org/10.3201/eid1108.041197>
9. NovIELLO S, Gallo R, Kelly M, Limberger RJ, DeAngelis K, Cain L, et al. Laboratory-acquired brucellosis. *Emerg Infect Dis*. 2004;10(10):1848-1850. <https://doi.org/10.3201/eid1010.040076>
10. Adesokan HK, Alabi PI, Stack JA, Cadmus SIB. Knowledge and practices related to bovine brucellosis transmission amongst livestock workers in Yewa, south-western Nigeria. *J S Afr Vet Assoc*. 2013;84(1):E1-E5. <https://doi.org/10.4102/jsava.v84i1.121>
11. Madzingira O, Byaruhanga C, Fasina FO, van Heerden H. Assessment of knowledge, attitudes and practices relating to brucellosis among cattle farmers, meat handlers and medical professionals in Namibia. *Vet Med Sci*. 2023;9(1):535-547. <https://doi.org/10.1002/vms3.937>
12. Shome R, Kalleshmurthy T, Shankaranarayana PB, Giribattavar P, Chandrashekar N, Mohandoss N, et al. Prevalence and risk factors of brucellosis among veterinary health care professionals. *Pathog Glob Health*. 2017;111(5):234-239. <https://doi.org/10.1080/20477724.2017.1345366>
13. Ghseini G, Ezzeddine Z, Tokajian S, Khoury CA, Kobeissy H, Ibrahim J-N, et al. Brucellosis: Bacteriology, pathogenesis, epidemiology and role of the metallophores in virulence: A review. *Front Cell Infect Microbiol*. 2025;15:1621230. <https://doi.org/10.3389/fcimb.2025.1621230>
14. National Bureau of Statistics (NBS). National Agricultural Sample Survey (NASS) 2022/2023 Report. Abuja. National Bureau of Statistics. 2025. <https://microdata.nigerianstat.gov.ng/index.php/catalog/173>
15. Ducrotoy MJ, Bertu WJ, Ocholi RA, Gusi AM, Bryssinckx W, Welburn S, et al. Brucellosis as an emerging threat in developing economies: Lessons from Nigeria. *PLoS Negl Trop Dis*. 2014;8(7):e3008. <https://doi.org/10.1371/journal.pntd.0003008>
16. Baba MM, Sarkindared SE, Baba SS. *Brucella* antibodies among abattoir workers, butchers and housewives in Maiduguri, Borno State, Nigeria. *Journal of Arid Zone Fisheries*. 2001;2(1):36-40.
17. Elelu N, Yakub-Obalolu BA, Chinedu NR, Odetokun IA, Al-Mustapha AI. Risk perception, seroprevalence, and real-time PCR detection of *Brucella* among pyretic patients and domestic animals in Kwara State, Nigeria. *Sci Rep*. 2025;15(1):10392. <https://doi.org/10.1038/s41598-025-94970-7>
18. Bruce D. Note on the discovery of a microorganism in Malta fever. *Practitioner*. 1887;39(3):161-170.
19. Wyatt HV. How Themistocles Zammit found Malta Fever (brucellosis) to be transmitted by the milk of goats. *J R Soc Med*. 2005;98(10):451-454. <https://doi.org/10.1258/jrsm.98.10.451>
20. World Health Organization. Brucellosis. 2020. Available from: <https://www.who.int/news-room/fact-sheets/detail/brucellosis>. Accessed 2026 Feb 10
21. Corbel MJ. Brucellosis in humans and animals. Geneva. World Health Organization. 2006.
22. Rossetti CA, Arenas-Gamboa AM, Maurizio E. Caprine brucellosis: A historically neglected disease with significant impact on public health. *PLoS Negl Trop Dis*. 2017;11(8):e0005692. <https://doi.org/10.1371/journal.pntd.0005692>
23. Kahariri SM, Kitale PM, Muchemi GM, Njenga K, Nanyingi M. Sero-prevalence and risk factors for human brucellosis in Marsabit county, Kenya (2014). *PAMJ-One Health*. 2021;4:9. <https://doi.org/10.11604/pamj-oh.2021.4.9.27024>
24. Njeru J, Wareth G, Melzer F, Henning K, Pletz MW, Heller R, et al. Systematic review of brucellosis in Kenya: Disease frequency in humans and animals and risk factors for human infection. *BMC Public Health*. 2016;16(1):853. <https://doi.org/10.1186/s12889-016-3532-9>
25. Tumwine G, Matovu E, Kabasa JD, Owiny DO, Majalija S. Human brucellosis: Sero-prevalence and associated risk factors in agro-pastoral communities of Kiboga District, Central Uganda. *BMC Public Health*. 2015;15(1):900. <https://doi.org/10.1186/s12889-015-2242-z>
26. Mehari S, Zerfu B, Desta K. Prevalence and risk factors of human brucellosis and malaria among patients with fever in malaria-endemic areas, attending health institutes in Awra and Gulina district, Afar Region, Ethiopia. *BMC Infect Dis*. 2021;21(1):942. <https://doi.org/10.1186/s12879-021-06654-y>
27. Lyimo B, Hugbo E, Mathew C, Mayenga C, Lukumbagire AH, Lyimo S, et al. Seroprevalence and risk factors for brucellosis amongst livestock and humans in a multi-herd ranch system in Kagera, Tanzania. *Front Public Health*. 2024;12:1478494. <https://doi.org/10.3389/fpubh.2024.1478494>
28. Aworh MK, Okolocha E, Kwaga J, Fasina F, Lazarus D, Suleman I, et al. Human brucellosis: Seroprevalence and associated exposure factors among abattoir workers in Abuja, Nigeria-2011. *Pan Afr Med J*. 2013;16:103. <https://doi.org/10.11604/pamj.2013.16.103.2143>
29. Cadmus SIB, Ijagbone IF, Oputa HE, Adesokan HK, Stack JA. Serological survey of brucellosis in livestock animals and workers in Ibadan, Nigeria. *Afr J Biomed Res*. 2006;9(3):163-168. <https://doi.org/10.4314/ajbr.v9i3.48900>
30. Bamidele F, Gidado S, Edukugbo A, Cadmus SIB. Seroprevalence of brucellosis in abattoir workers and slaughtered cattle in Ilorin metropolis Kwara State Nigeria. *Int J Infect Dis*. 2020;101:532-533. <https://doi.org/10.1016/j.ijid.2020.09.1379>
31. Igawe PB, Okolocha E, Kia GS, Irmia IB, Balogun MS, Nguku P. Seroprevalence of brucellosis and associated risk factors among abattoir workers in Bauchi State, Nigeria. *Pan Afr Med J*. 2020;35:33. <https://doi.org/10.11604/pamj.2020.35.33.18134>
32. Adamu NB, Adeniyi SO, Adamu SG, Bale JOO, Okoh AEJ, Umaru GA, et al. Seroprevalence of brucellosis among livestock workers at Maiduguri cattle market, Borno State, North Eastern, Nigeria. *J Public Health Epidemiol*. 2015;7(8):253-257. <https://doi.org/10.5897/JPHE2015.0738>
33. Cadmus S, Salam SP, Adesokan HK, Akporube K, Ola-Daniel F, Awosanya EJ. Seroprevalence of brucellosis and Q fever infections amongst pastoralists and their cattle herds in Sokoto State, Nigeria. *PLoS One*. 2021;16(7):e0254530. <https://doi.org/10.1371/journal.pone.0254530>
34. Junaidu AU, Oboegbulem SI, Salihu MD. Seroprevalence of brucellosis in Prison Farm in Sokoto, Nigeria. *Asian J Epidemiol*. 2008;1(1):24-28. <https://doi.org/10.3923/aje.2008.24.28>
35. Kim S, Lee DS, Watanabe K, Furuoka H, Suzuki H, Watarai M. Interferon- γ promotes abortion due to *Brucella* infection in pregnant mice. *BMC Microbiol*. 2005;5(1):22. <https://doi.org/10.1186/1471-2180-5-22>

36. Ayoola MC, Akinseye VO, Cadmus E, Awosanya E, Popoola OA, Akinyemi OO, et al. Prevalence of bovine brucellosis in slaughtered cattle and barriers to better protection of abattoir workers in Ibadan, South-Western Nigeria. *Pan Afr Med J*. 2017;28:68. <https://doi.org/10.11604/pamj.2017.28.68.10925>
37. Halilu H, Giwa FJ, Ahmed SA, Sufiyan MB, Mohammed AI. Seroprevalence and factors associated with risk of human brucellosis among febrile patients attending health-care facilities in Bauchi, North-Eastern Nigeria. *Ann Trop Pathol*. 2020;11(2):107-112.
38. Momoh HA, Ijale GO, Ajogi I, Okolocha EC. Risk factors and level of awareness of canine brucellosis in Jos, Plateau State, Nigeria. *J Vet Med Anim Health*. 2015;7(2):39-44. <https://doi.org/10.5897/JVM AH2014.0333>
39. Hasanain A, Mahdy R, Mohamed A, Ali M. A randomized, comparative study of dual therapy (doxycycline–rifampin) versus triple therapy (doxycycline–rifampin–levofloxacin) for treating acute/subacute brucellosis. *Braz J Infect Dis*. 2016;20(3):250-254. <https://doi.org/10.1016/j.bjid.2016.02.004>
40. Alavi SM, Alavi L. Treatment of brucellosis: A systematic review of studies in recent twenty years. *Caspian J Intern Med*. 2013;4(2):636-641.
41. Akinyemi KO, Fakorede CO, Amisu KO, Wareth G. Human and animal brucellosis in Nigeria: A systemic review and meta-analysis in the last twenty-one years (2001–2021). *Vet Sci*. 2022;9(8):384. <https://doi.org/10.3390/vetsci9080384>
42. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71. <https://doi.org/10.1136/bmj.n71>
43. Morgan RL, Whaley P, Thayer KA, Schünemann HJ. Identifying the PECO: A framework for formulating good questions to explore the association of environmental and other exposures with health outcomes. *Environ Int*. 2018;121(1):1027-1031. <https://doi.org/10.1016/j.envint.2018.07.015>
44. Luchini C, Stubbs B, Solmi M, Veronese N. Assessing the quality of studies in meta-analyses: Advantages and limitations of the Newcastle Ottawa Scale. *World J Meta-Anal*. 2017;5(4):80-84. <https://doi.org/10.13105/wjma.v5.i4.80>
45. Biggerstaff BJ, Tweedie RL. Incorporating variability in estimates of heterogeneity in the random effects model in meta-analysis. *Stat Med*. 1997;16(7):753-768. [https://doi.org/10.1002/\(SICI\)1097-0258\(19970415\)16:7<753::AID-SIM494>3.0.CO;2-G](https://doi.org/10.1002/(SICI)1097-0258(19970415)16:7<753::AID-SIM494>3.0.CO;2-G)
46. Schwarzer G, Rücker G. Meta-analysis of proportions. In: Evangelou E, Veroniki AA, editors. *Meta-Research: Methods and Protocols*. New York, NY: Humana. 2022. p. 159-172. https://doi.org/10.1007/978-1-0716-1566-9_10
47. Huedo-Medina TB, Sánchez-Meca J, Marín-Martínez F, Botella J. Assessing heterogeneity in meta-analysis: Q statistic or I² index? *Psychol Methods*. 2006;11(2):193-206. <https://doi.org/10.1037/1082-989X.11.2.193>
48. Aslam M. Cochran's Q test for analyzing categorical data under uncertainty. *J Big Data*. 2023;10(1):147. <https://doi.org/10.1186/s40537-023-00823-3>
49. Agada CA, Mohammed J, Okoh AE, Ogugua JA. Prevalence and risk factors associated with brucellosis among high-risk individuals in Lafia, Nasarawa State, Nigeria. *Int J One Health*. 2018;4(1):45-51. <https://doi.org/10.14202/IJOH.2018.45-51>
50. Atsanda NN, Liba JW, Francis MI, Malgwi HA. Serological survey of brucellosis among internally displaced persons in Maiduguri, northeastern Nigeria. *Sokoto J Vet Sci*. 2018;16(3):61-65. <https://doi.org/10.4314/sokjvs.v16i3.9>
51. Thomas KM, Mispha T, Anthony TJ. Seroprevalence of brucellosis among febrile patients negative for malaria and typhoid attending Jos University Teaching Hospital Plateau State, Nigeria. *UMYU J Microbiol Res*. 2025;10(2):125-130. <https://doi.org/10.47430/ujm r.25102.014>
52. Ofukwu AR, Yohanna CA, Abuh HA. *Brucella* infection among hospital patients in Makurdi, North Central Nigeria. Available from: <https://www.priory.com/med/brucella.htm>. Accessed 2026 Aug 15
53. Folagbade OB, Adesiyun AG, Olayinka AT, Randawa A, Bawa U. Seroprevalence of brucellosis among women with miscarriage at Ahmadu Bello University Teaching Hospital, Zaria. *Trop J Obstet Gynaecol*. 2017;34(2):145-151. https://doi.org/10.4103/TJOG.TJOG_29_17
54. Ogbodo SO, Isiofia OP, Uzodinma BA. Co-existence and seroprevalence of brucellosis in a malaria-endemic metropolis of south-eastern Nigeria. *J Exp Res*. 2016;4(2):68-73.
55. Eko SM, Esemu SN, Nota AD, Ndip LM. A review on brucellosis in Cameroon: Diagnostic approaches, epidemiology and risk factors for infection. *Adv Microbiol*. 2022;12(7):415-442. <https://doi.org/10.4236/aim.2022.127030>
56. Billard E, Cazevieuille C, Dornand J, Gross A. High susceptibility of human dendritic cells to invasion by the intracellular pathogens *Brucella suis*, *B. abortus*, and *B. melitensis*. *Infect Immun*. 2005;73(12):8418-8424. <https://doi.org/10.1128/IAI.73.12.8418-8424.2005>