Epidemiology of Newcastle disease in chickens of Ethiopia: a systematic review and meta-analysis

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Abstract

The objective of this systematic review was to estimate the overall pooled prevalence of Newcastle disease in chickens in Ethiopia and identify the sources of heterogeneity among and within studies. The seroprevalence of Newcastle disease was estimated using a single-group meta-analysis. Attempts were also made to identify study-level variables that could explain the heterogeneity in the apparent seroprevalence of the Newcastle disease. The findings were based on 16 published articles and 33 district-level reports and were limited to studies performed during 2005–2017. Due to the presence of heterogeneity, pooled analysis from different districts was conducted using random-effects meta-analysis. The single-group summary of Newcastle disease seroprevalence in chickens was estimated to be 21.47% (19.54–23.4%) with a 95% confidence interval. Our results indicated high inter-study variability (Cochran’s $Q$ statistic = 196.2, true variance ($\tau^2$) = 0.36, inverse variance index ($I^2$) = 90.0%, $p < 0.001$). Of all variables analysed, diagnostic techniques and regions were the most significant predictors ($p < 0.05$) of heterogeneity. According to the diagnostic technique-based meta-analysis of random pooled prevalence, the haemagglutination inhibition test had the highest prevalence, followed by the enzyme-linked immunosorbent assay. In conclusion, the high-pooled prevalence estimates of the disease, combined with the scarcity of published data for the entire country of Ethiopia, indicate a significant data gap on the distribution of Newcastle disease in the country. While the high pooled prevalence tells the need for intervention to control the disease, there is also a need to assess the disease prevalence in all other parts of the country.

Keywords Chickens · Ethiopia · Meta-analysis · Newcastle disease · Pooled prevalence

Introduction

Poultry is the world’s largest livestock group, accounting for approximately 23.39 billion chickens, ducks, and turkeys, with chickens alone accounting for 1 billion (Food and Agriculture Organization (FAO), 2016). In developing countries, poultry production has significant economic, social, and cultural benefits. It plays an important role in supplying essential amino acids for human consumption (Yoriyo et al., 2008). The contribution of poultry to global animal protein sources is expected to reach 40% by 2020, with a significant increase anticipated in the developing world (Delgado et al., 1999). According to Ethiopian Central Statistical Authority (CSA), the total poultry population has increased, and now it is estimated to be more than 60 million (CSA, 2018; FAO, 2016; Reta, 2009). Chicken contributes significantly to food security and livelihood improvement (Addis et al., 2014; Dessie et al., 2013; Melesse and Negesse, 2011). It constitutes approximately 28–30% of all animal protein sources worldwide (FAO, 2012; Shapiro et al., 2015).

However, farming intensification increases the risk and susceptibility of chickens to production diseases (European Commission, 2018a). Production diseases have a negative impact on animal health and welfare, cause inefficiencies that reduce profitability and product quality, and increase the environmental footprint and antibiotic use. Such infections...
are estimated to lower the efficiency of poultry systems by 10–15% (European Commission, 2018a). Due to this condition, economic losses are significant in all countries, including the European Union countries. Many production diseases can also be transmitted all through the food chain. As a result, production diseases will continue to be the most pressing concern for global poultry production (Hafez and Attia, 2020). In addition, consumer distrust about the quality and safety of poultry meat and poultry products will remain a crucial challenge for the poultry industry and its long-term strategic prospects (Hafez, 2010).

The European Union has initiated and implemented several programs, regulations, and recommendations to address these issues. One of the essential normative acts adopted by the European Union was the Commission Implementing Decision (EU) 2018/945 of June 22, 2018, on infectious diseases and related special health issues to be covered by epidemiological surveillance and relevant case definitions (European Commission, 2018b). The high microbiological risk of raw poultry has been a focus of European Union regulations over the last decade (Bondoc, 2014, 2016a, b). According to European regulations in the Veterinary Sanitary and Food Safety report (Bondoc, 2016a), combating, monitoring, surveying, and eradicating certain infectious diseases is essential to ensure consumer interest and food wellbeing. Such an agricultural policy intends to safeguard producers’ and consumers’ interests through economic and social means (Bondoc, 2016b).

Among the various infectious diseases threatening poultry productivity, Newcastle disease (ND) is a disease listed by the World Organisation for Animal Health (OIE) due to its potential for severe and rapid spread (OIE, 2021). It is a highly contagious, acute viral disease of domestic poultry and other bird species, regardless of variations in sex and age (Alexander, 2013; Haque et al., 2010; Iram et al., 2014; Orsi et al., 2010). ND is caused by virulent strains of avian paramyxovirus belonging to the family Paramyxoviridae with the genus Avulavirus (Choi et al., 2010; Mayo, 2002; Qin et al., 2008; Yu et al., 2001). Newcastle disease virus (NDV) strains have been classified into three groups, based on their pathogenicity in infected chickens: high virulence (velogenic), moderate virulence (mesogenic), and low virulence (lentogenic) (Alexander and Senne, 2008). The disease presents as respiratory and gastrointestinal problems, nervous system impairment, and reproductive complications (Nanthakumar et al., 2000; Tiwari et al., 2004).

The high mortality and morbidity associated with the disease cause significant economic losses. According to Alexander et al. (2004), this disease causes up to 80% of poultry deaths in rural areas globally and restricts rural economic development. The disease also has a significant economic impact on the global poultry industry (Aldous et al., 2003; Diel et al., 2012; Qin et al., 2008). Humans too can be affected by NDV. When humans come in contact with a high viral load, they contract conjunctivitis (Alexander, 2000). People involved in laboratory work, chicken production, and chicken vaccination are more susceptible.

Newcastle disease, named after the city of Newcastle in England, first appeared in wild birds in Scotland more than 150 years ago (Kuiken, 1999; Macpherson, 1956). It was first identified in poultry in the 1920s in Indonesia and England and is now endemic in many countries (Awan et al., 1994). Epidemics are most commonly observed in Central and South America, Africa, and Asia. The threat of ND is still present in Europe where outbreaks occur on a sporadic basis. ND first appeared on the African continent in the 1930s and 1940s (Miguel et al., 2013). Newcastle disease in Ethiopia was first reported in 1971 on a small poultry farm in Asmara, then part of Ethiopia (Bakwe et al., 1991) and has since been regarded as the primary constraint to Ethiopian chicken production (Sambo et al., 2014). The veterinary department’s reports to the World Organization for Animal Health revealed an average of 50 outbreaks per year from 2005 to 2015 (World Animal Health Information Database (Wahid), 2016).

There are published reports from various regions of Ethiopia, but there is no summarized information on the prevalence of the disease. Thus, meta-analysis is an appropriate statistical technique for assessing a large collection of analysis results from individual studies to integrate the findings (Dohoo et al., 2009) and has been used to summarize scientific evidence from the literature. Furthermore, meta-synthesis and systematic reviews help to overcome some of the limitations of individual study precision. These methods served the purpose of this review, which was to estimate the overall pooled prevalence of NDV in Ethiopia based on published reports, as well as to investigate the reasons that may contribute to the source of heterogeneity, both inter- and intra-studies.

Materials and methods

This systematic review protocol was adapted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement guidelines of Moher et al. (2009). The guidelines included publication search strategy, inclusion criteria, the review process, data extraction procedure, and data analysis.

Publication search strategy

The first and last authors conducted independent literature searches from published data using the keywords Newcastle disease, Newcastle disease in chickens, Prevalence of Newcastle disease in chickens, and Prevalence of Newcastle disease in Ethiopian chickens. We searched PubMed,
Google Scholar, African Journal of Online (AJO), National Center for Biotechnology Information (NCBI), PubMed Central (PMC), Scopus, Web Science, and cross-reference list databases for published literature and found 15, 232, 3, 6, 127, 52, 19, and 2 articles, respectively. Among the publications retrieved using these keywords were those related to the apparent prevalence of Newcastle disease in Ethiopian chickens.

Inclusion criteria

The inclusion criteria comprised publication type (peer-reviewed journals), language (English), study design (cross-sectional), study area (Ethiopia), sampling procedure (random), and timeframe (published between 2005 and 2017).

Review protocol and process

The titles and abstracts of all publications retrieved during the searches were initially reviewed using the inclusion criteria and preliminary assessment tool (annexed in the Supplementary materials) and considered for the subsequent full-text assessment stage. Finally, to select eligible studies for data extraction, a critical assessment of the full text was performed, employing the secondary assessment tool (annexed in the Supplementary materials). The review was done twice by two independent researchers to eliminate bias in study selection.

Data extraction

After the screening procedure, data were extracted from each of the selected articles. The variables sampling procedure, type of design used, sex, age, district, administrative zone, region, author’s name, year of publication, type of diagnostic techniques used, and apparent prevalence were extracted across the studies.

Pooled prevalence estimate

The apparent prevalence point estimate of the disease was taken from individual studies \(i\). The number of positive samples was divided by sample size to calculate the logit prevalence (effect size). The logit transformation was used to normalize the distribution of the outcome variable, and standard error (SE) was calculated using the following formula:

\[
SE_i = \sqrt{\frac{1}{n \times p_i \times (1 - p_i)}}, \quad \text{logit prevalence} = \ln\left(\frac{p_i}{1 - p_i}\right)
\]

where SE = standard error; \(n\) = sample size, \(\ln\) = natural logarithm; and \(p\) = study level prevalence estimate.

Test of heterogeneity

Random-effects meta-analyses and modeling of logit-transformed prevalence data were performed using the method developed by DerSimonian and Laird (1986). An estimate of heterogeneity among and within the studies was taken from the inverse variance of the random-effects model (Borenstein et al., 2009; Dohoo et al., 2009; Hedges and Vevea, 1998). Inter-study heterogeneity was evaluated using Cochran’s \(Q\) statistic, \(\tau^2\), and \(\tau^2\).

\[
Q = \sum \left(\frac{w_i \times ES_i^2}{\sum w_i}\right) - \left[\left(\frac{\sum (w_i \times ES_i)^2}{\sum w_i}\right)^2\right], \quad w_i = \text{weight of individual study; } i = \text{an individual study’s apparent prevalence point estimate of the disease; and } ES = \text{effect size/logit prevalence.}
\]

The inverse variance index \((I^2)\) expresses true heterogeneity between studies based on the percentage of total inter-study variations observed. \(I^2\) value of 0% indicated no observed heterogeneity, whereas values of 25%, 50%, and 75% indicate low, moderate, and substantial heterogeneity, respectively (Higgins and Thompson, 2002). \(I^2\) quantifies the variance of the true effect sizes among the studies. When we take the square root of \(I^2\), we obtain \(r\), which is the standard deviation of the true effect sizes.

\[
I^2 = \frac{Q - df_s}{Q} \times 100, \quad df_s = \text{degree of freedom } (n - 1), \quad n = \text{number of studies, and } Q = \text{Cochran’s } Q \text{ statistic.}
\]

Individual study weights \((w_i)\) were also computed as the inverse of its variance, \(w_i = \frac{1}{SE^2}\) explained proportion of inter-study variance was estimated as follows:

\[
\text{Adjusted } R^2 = 1 - \frac{r^2_{\text{unexplained}}}{r^2_{\text{explained}}}, \quad R^2 = \text{explained percentage proportion of between-study variance.}
\]

Subgroup and meta-regression analysis

Subgroup analyses were performed to determine potential sources of inter-study homogeneity. A 95% exact binomial distribution was used for point estimation of the explanatory variables. Predictor variables such as region, diagnostic techniques, and sample size were incorporated for quantitative synthesis.

Data analysis

The extracted data were cleaned and edited in Microsoft Excel (2007 version), and then imported to and analysed in STATA 14 software (StataCorp, 2015). In all of the analyses, statistical significance was set at \(p\) value < 0.05.

Results

Spatial distribution of the selected articles

The district-level studies included in the systematic review and meta-analysis primarily covered the country’s central
parts and some parts of northern Ethiopia. Figure 1 depicts a map of the geographical area of the districts included in this review.

**Number of identified and reviewed studies**

From the search engines mentioned in the “Publication search strategy” section, about 456 publications were identified, of which 10 publications were removed because they were duplicate records. The remaining 446 publications’ titles and abstracts were reviewed considering the inclusion criteria and preliminary review tool. Of the 446 publications, 417 had excluded as they did not meet the inclusion criteria and preliminary assessments. Following a critical appraisal of the full text of the remaining 29 publications, 16 studies were found eligible for data extraction and included in the review (Fig. 2).

**Descriptive result of the eligible studies**

The eligible studies were selected from five administrative regions of Ethiopia: Amhara, Oromia, Tigray, Addis Ababa, and the Southern Nation, Nationalities, and People’s Region. These 16 studies reported the apparent prevalence of Newcastle disease in chickens at the district level, resulting in the analysis of 5870 test samples. The sample sizes ranged from 146 to 1314 chickens. Eleven of the 16 studies reported multiple prevalence estimates (estimates from the same region in different districts), and each report was counted as an independent study. As a result, this analysis included 34 studies in total. The prevalence estimates of the disease at the district level ranged from 5.6 to 38.8%, with an overall pooled prevalence of 21.47%. The diagnostic techniques used in the selected studies include the haemagglutination inhibition (HAI) test, Svanovir NDV-Ab ELISA, blocking enzyme-linked immunosorbent assay (B-ELISA), competitive-ELISA (C-ELISA), and polymerase chain reaction (PCR) (Table 1).
Univariable and multivariable meta-regression

From the three predictor variables, the univariable meta-regression revealed that there were statistically significant differences among regional states and diagnostic techniques used ($p < 0.05$). Compared to the HAI test, PCR had a significant decrease in effect size by $-1.56$ with a $p$ value of 0.00, while ELISA showed a decrease of $-0.47$. ELISA was statistically different from the HAI test ($p < 0.05$). Regional states accounted for 95% of the inter-study variance ($\tau^2 = 0.44$).

Results based on $p$ values, $I^2$, and $\tau^2$ from district-level multivariate and univariate meta-regression are presented in Table 2.

Subgroup and meta-regression analysis

Newcastle disease pooled seroprevalence in chicken was estimated to be 21.5% based on a single-group analysis. From this analysis, the estimated pooled prevalence for HAI test, PCR, and ELISA was calculated to be 23.3%, 6.4%, and 19.2%, respectively. Across the region, the pooled prevalence was 21.9%, 26.2%, 10.1%, 19.8%, and 17% for the Oromia, Tigray, Addis Ababa, Southern Nations, Nationalities, and People’s Region, and Amhara regions, respectively. The values of $Q$, $\tau^2$, and $I^2$ for each category are listed in Table 3.

Heterogeneity of Newcastle disease at district level by authors’ report

A forest plot showing the result of district-level individual study along with effect size and their respective weights is presented in Fig. 3. The effect size of the pooled logit prevalence result of random effect meta-analysis was $-1.86$ (95% CI $-2.11$, $-1.61$). The weights of individual district-level studies ranged from 1.99 to 3.63%, which are close to each other. The logit prevalence estimates also indicated a high proportion of inter-study variance ($I^2 = 83.2\%, p < 0.001$).

Heterogeneity of Newcastle disease by diagnostic technique

Diagnostic technique-based subgroup analysis of logit prevalence estimates was performed to visualize the effect of the type of diagnostic techniques used in studies in a forest plot (Fig. 4). The percentages of observed total variation between studies that were attributed to true heterogeneity...
in the HAI test, ELISA, and PCR were 73.7% (p < 0.001), 29.1% (p < 0.001), and 66.0% (p < 0.001), respectively.

The effect size of the meta-regression analysis was performed, both with and without controlling for sample size, in parallel to each explanatory variable. An overall meta-regression analysis result revealed that the diagnostic techniques explained 27.97% and 26.22% of the inter-study variations, with and without controlling the sample size, respectively (Table 4).

### Discussion

This report is the first systematic review and meta-analysis work on Newcastle disease in chickens that reports pooled disease prevalence estimates in Ethiopia. The review included data from 16 cross-sectional studies that reported 34-point prevalence district-level estimates and involved 5870 samples in total. According to the review, there was very little research on Newcastle disease in chickens until around 2017. The majority of the studies were conducted...
in central parts of Ethiopia, leaving significant gaps in the literature on NDV in other parts of the country. The fact that the central parts of the country are closer to the national animal health diagnostic and investigation center, many universities, and other research institutes is likely one of the reasons for the research focus in these areas. However, the country’s total poultry population has increased, and poultry production is now widespread all over the country. As a result, there is an urgent need to expand poultry disease research throughout the country.

The reported apparent seroprevalence of the disease ranged from 5.6% (Belayneh et al., 2014) to 38.8% (Mulualem Ambaw, 2017). Such range is attributed to differences in the management system, the number of samples taken, the timing of sampling, agroecology, stage of infection, and diagnostic tests used. The overall pooled effect size summary result of the meta-analysis was found to be 21.47%
(19.54–23.4% of 95% CI). The pooled summary of logit transformed an effect size estimate of \(-1.857 (-2.11, -1.61)\). The meta-analysis of the effect size of the random-effects model revealed the existence of a substantial difference between studies that cannot be attributed to chance. The percentage value of the inverse variance square (83.2%, \(p = 0.000\)) revealed true variability and high heterogeneity. The use of different diagnostic techniques and the presence of small sample sizes in our analysis might well have contributed to lower precision of an individual prevalence estimate and additional heterogeneity among studies.

The pooled prevalence estimate varied significantly between regions and was found higher and statistically significant in Tigray (26.2%; \(p < 0.001\)) than in the other regions. Variations in prevalence across regions could also be attributed to ecological characteristics of a specific area, such as climate, settlement pattern, sanitary and socioeconomic practices, which may facilitate disease spread, as well as the season in which the study was conducted (McCalum et al., 2001). According to Orajaka et al. (1999), differences in the stages of the epidemic cycle and the ecology between areas can affect viral viability in the environment. The studies were also mostly conducted mainly in nearby and accessible areas, so remote areas may have been under-represented. Even if the disease is known to be endemic to other regions, no study has been reported from the Gambela, Afar, and Benishangul Gumuz regions.

The types of diagnostic test explained 27.97% of the explainable proportion of heterogeneity between the studies. The pooled estimated prevalence of the disease in the HAI (23.3% [22.0, 24.7]) and ELISA (19.2% [17.5, 20.9]) tests were significantly higher (\(p < 0.05\)) than those of PCR (6.4% [4.4, 8.9]). The results of our study disagree with those of other studies, which have found that PCR is more sensitive than HAI and ELISA for early detection of NDV (Mohammed et al., 2013). This might be associated with the higher number of samples analysed in the HAI test and the time of sampling being at a later stage of infection. ELISA is highly sensitive, utilizes the whole virus as antigens, and yields results that correlate well with HAI test results. ELISA kits can potentially detect antibodies directed against all proteins in the NDV particles. When the virus mutates, monoclonal antibody-based ELISAs may not be able to detect certain strains of the NDV (Ge et al., 2016). In HAI tests, only antibodies directed against haemagglutinin and neuraminidase proteins are detected. Diagnosis of NDV by molecular tests, especially by using reverse transcriptase and real-time polymerase chain reaction, can rapidly and accurately detect the viral genome in clinical samples with high sensitivity (Bello et al., 2018).
The percentage of total observed inter-study variations that were due to true heterogeneity was higher in the HAI test (73.7%; $p = 0.000$) as compared to other tests, which could be associated with the variation in HAI cut-off values used for the interpretation of the results. For example, some authors considered an HAI titer $\geq 1\log_2$ as positive (Biswas et al., 2009; Bouzari and Mousavi, 2006), whereas others used cut-off titers of $\geq 3\log_2$ (Tadese et al., 2005; Zeleke et al., 2005).

The study has some limitations. An overall analysis of the study showed a large degree of heterogeneity among studies and within subgroup analysis. Therefore, the study may not necessarily reflect the real situation of a country’s disease status. The studies used in this analysis did not cover all the chicken-raising areas of the country. Moreover, they lacked complete information on important factors such as season, agro-ecology, and the age of animals. The absence of unpublished data in the meta-analysis also limited the reflection on...
Table 4 Proportion of each predictor variable and associated statistical significance for observed heterogeneity among reports of Newcastle disease prevalence in chickens

| Variables        | Without sample size | With sample size |
|------------------|---------------------|------------------|
|                  | R²                  | p value     | R²                  | p value     |
| Sample size      | –                   | –           | 3.21%               | < 1.0       |
| Regional states  | 0.00%               | < 0.001    | 1.78%               | < 0.001     |
| Diagnostic technique | 27.97%           | < 0.01     | 26.22%               | < 0.01      |
| Sex              | 13.40%               | < 0.5      | 10.40%               | < 0.5       |

R² (adjusted): explained percentage proportion of between-study variance

the epidemiology of the disease in Ethiopia. Furthermore, the disease itself occurs in the form of an outbreak in different parts of the country. Our study has covered a long period (2005–2017) because of the scarcity of cross-sectional data.

To conclude, the disease’s pooled prevalence estimate is high, but there is higher variability among studies, regions, and diagnostic tests. The estimated pooled prevalence was highest in haemagglutination inhibition diagnostic test and Oromia region. The administrative regional states and diagnostic techniques are the major contributing factors for the occurrence of Newcastle disease. There is also high heterogeneity in the prevalence of the disease among the individual studies and the type of diagnostic test used.

This study adds to the current scientific knowledge that a high prevalence of Newcastle disease in chickens exists in Ethiopia. This information is primarily helpful for decision-makers, chicken producers, and other beneficiaries, and it can assist in developing appropriate prevention and control strategies for the disease in the future. However, most of the studies were conducted in the central parts of Ethiopia, and there is a significant knowledge gap in other parts of the country. Even though the number of studies in the country is insufficient, the high prevalence of the disease requires prompt attention of all stakeholders in the sector to bring it under control through comprehensive disease prevention and control intervention strategies.

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Data availability Data available on request from the authors.

Declarations Conflict of interest The authors declare no competing interests.

Additional information No additional information is available for this paper.

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