Peste des petits ruminants (PPR) in Africa and Asia: A systematic review and meta-analysis of the prevalence in sheep and goats between 1969 and 2018

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Abstract

Background: Peste des petits ruminants (PPR) is a prevalent viral disease of sheep and goats that impacts productivity and international animal trade. Despite the substantial economic consequences related to PPR, little is known about the prevalence of this disease at the broad geographical levels.

Objective: The present study aimed to use a systematic approach to assess the regional prevalence of PPR in sheep and goats, and the associated factors that contribute to prevalence estimates.

Methods: Published articles on PPR in sheep and goats were searched in PubMed, Web of Science, Scopus, Google Scholar and the reference lists of articles reporting the prevalence from 1 January 1969 to 31 December 2018. Articles were selected using inclusion and exclusion criteria. Since the heterogeneity among the studies was significant, pooled prevalences were estimated by a random effect meta-analysis model.

Results: Data on the prevalence of PPR were obtained from Africa and Asia, where the pooled prevalence estimates were 40.99% (95% CI: 37.20%–44.79%) and 38.43% (95% CI: 35.64%–41.22%) respectively. Overall, the estimated pooled prevalence at Africa-Asia level in sheep was 39.31% (95% CI: 35.75%–42.88%) and in goats was 39.57% (95% CI: 36.66%–42.48%). Significant heterogeneity ($I^2 > 80\%$) was noted in most pooled estimates.

Conclusion: The results on the regional prevalence estimates of PPR presented here will be useful in raising awareness and advocating for Governments to engage in initiatives to eradicate PPR and prevent it from spreading to other continents.

KEYWORDS

epidemiology, infectious disease, meta-analysis, PPR, ruminant
Peste des petits ruminants (PPR) is an economically significant and widespread viral disease of ruminants that is caused by Peste des petits ruminants virus, a Morbillivirus that belongs to the family Paramyxoviridae (Gibbs, Taylor, Lawman, & Bryant, 1979). PPR spreads quickly in susceptible ruminant species, and the highest number of outbreaks occurs in sheep and goats. Cattle, camels and several wild ruminants have been infected occasionally; however, there is currently no evidence to show that the disease is maintained in these populations without concurrent infection in sheep or goats (Lembo et al., 2013). PPR is considered to be the most significant economic threat to the development of sustainable sheep and goat production across the developing world, particularly in Africa and Asia. For example, in India, the estimated annual loss caused by PPR in sheep and goats was about US$ 1.297 million per year (Singh, Bardhan, Verma, Prasad, & Sinha, 2014), while in the Turkana County of Kenya, it was US$ 19.1 million (Kihu, Gitao, et al., 2015). Moreover PPR affects national and international movement and trade of sheep and goats and their products. The disease is currently considered as one of the main transboundary and notifiable disease that constitutes an emerging or re-emerging threat in many countries of the world. In March 2015, PPR was targeted as a high priority disease for progressive control by the World Organisation for Animal Health (OIE) and the Food and Agriculture Organisation (FAO) to eradicate the disease by 2030.

PPR is also known as sheep and goat plague. The causative agent, Peste des petits ruminants virus (PPRV), is considered sensitive to abiotic environmental factors, and it does not survive long outside of a host. The virus is primarily transmit through aerosol and direct contact between infected and susceptible animals (Fournié et al., 2018). The incubation period of the disease is 4–6 days, but can be up to 14 days. Clinical infection varies, and may include fever, oculo-nasal discharges, oral erosions, pneumonia and diarrhoea (Naznin, Ahaduzzaman, Chowdhury, & Biswas, 2014). The infection period is usually 5–7 days, and death of the infected animal may occur within 10–12 days post-infection due to severe dehydration and respiratory failure (Diallo et al., 2007). Morbidity and mortality are usually high, and PPR can create epidemics that can cause up to 100% mortality in susceptible sheep and goat populations (Parida et al., 2016). In some cases, particularly in the mild form of the disease, affected animals develop coughing and diarrhoea, and spontaneous recovery may occur within 10–15 days of infection. The magnitude of the disease depends on several factors such as the virulence of the PPR virus strain, species of animal, age, gender, breed, host immune status and previous population exposure to PPRV (Abubakar, Rasool, et al., 2016). Sheep and goats in endemic regions may develop lifelong immunity following natural infection, but naïve animals may allow continuous circulation of the virus to establish an endemic situation (Mariner et al., 2016).

Since the discovery of PPR, there have been many advances in the diagnosis of PPR in sheep and goats, and diagnosis protocols range from symptomatic diagnosis to virus isolation (Banyard et al., 2010). The current diagnosis is based on clinical symptoms, pathological lesions and precise identification of PPRV antigen or antibody in various molecular or serological tests in biological samples (Balamurugan, Hemadri, Gajendragad, Singh, & Rahman, 2014). Virus isolation is the gold-standard for the diagnosis of PPR, but this is mostly impractical in the field (Banyard et al., 2010). As a morbillivirus, PPRV is antigenically similar to the viruses that cause rinderpest in cattle, measles in humans and distemper in dogs, but can be serologically distinguished by use of commercially available enzyme-linked immunoassay (ELISA) kits (Anderson & McKay, 1994). In many countries, diagnosticians are moving towards the use of molecular techniques such as polymerase chain reaction (PCR) for early and specific diagnosis of PPR in sheep and goats (Kgotlele, Kasanga, Kusiluka, & Misinzo, 2014). Adaptation of a method of diagnosis often depends on local facilities and availability of resources (Banyard et al., 2010).

The first report of PPR was made in the Ivory Coast, West Africa, in 1942. Today, PPR is quite common in both Africa and parts of Asia, and is emerging as a threat to other continents such as Europe (Parida et al., 2016). In recent decades, several scholarly narrative reviews of the distribution of PPRV lineages based on nucleoprotein and fusion genes sequence analysis for particular geographical regions have been published (Banyard et al., 2010; Dilli, Geidam, & Egwu, 2011; Parida et al., 2016). A comprehensive pooled prevalence estimate of PPR has not been reported, but a wide range of prevalence estimates of PPR in sheep and goats have been reported in various regions (Cêtre-Sossah et al., 2016; Jaisree et al., 2017; Li et al., 2017). Reasons for the inconsistent prevalence estimates of PPR could include an endemic situation of PPRV in a particular geographic area, differences in methods used for identifying the disease, origin of samples, sampling strategy, year of study, study duration and species of animal studied. An overview of knowledge on the regional prevalence of PPR in sheep and goats will offer a better understanding of the distribution of the disease and its impacts on animal production, and will be useful in disease control. This study aims to use a systematic review and meta-analysis approach to estimate the regional prevalence of PPR in sheep and goats, and to evaluate the potential factors that contribute to the variability in the prevalence and distribution of disease.

2 | METHODS

The study was conducted following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for systematic review and meta-analysis. The PRISMA 2009 checklist was used to ensure the inclusion of relevant information and maintain study standard (Appendix S1, Table S1).

2.1 | Search strategy

An optimized systemic search strategy was used to identify all published studies related to the prevalence of PPR in sheep and goats.
Published works were searched in four electronic web search engines: PubMed, Web of Science, Scopus and Google Scholar for articles, published between January 1969 and December 2018. The search was conducted on 25 February 2019. The search synonyms were used to search the literature with the following keywords: (Prevalence OR Incidence OR Frequency OR Detection OR Occurrence OR Identification OR Isolation OR Characterization OR Investigation OR Survey OR Rate) AND (PPR OR Peste des petits ruminants OR Goat plague OR Kata OR ovine rinderpest OR Caprine rinderpest) AND (Goat OR Doe OR Buck OR Caprine OR Ovine OR Sheep OR Ram OR Ewe OR small ruminant). Search field option was selected as “All fields”. A restriction was placed on the language of publication “English”. Search terms and keywords were adjusted according to minor differences in syntax rules of four electronic databases. The reference management software EndNote X8 (Clarivate Analytics, Philadelphia, PA) was used to organize and remove duplicate articles between the search engines. The reference lists of extracted articles were also searched manually in triplicate for additional potential articles and to ensure that selected databases searches did not miss any reports.

2.2 | Selection of studies

Articles were selected for meta-analysis based on the following criteria: published between January 1969 and December 2018; full-text article; published in English; any country of the world; studied population is sheep or goat or both; reported as animal level prevalence data; cross-sectional, case-control, longitudinal and cohort studies. Reasons for exclusion of articles were species other than sheep or goat, prevalence data not reported, case study or retrospective study, flock with a history of vaccination, comparison of methods, experimental trial and articles in languages other than English.

2.3 | Quality of the studies

Studies selected for this meta-analysis were assessed for quality of reporting and selection for bias using a quality assessment checklist (Ahaduzzaman, 2019; Hoy et al., 2012). The checklist included nine parameters which have "yes" and "no" applicable option. Operationally, the "yes" answer was awarded a score of 1; while "no" was provided with 0 scores. Ultimately, for each article, the mean score was determined. Articles were categorised as follows: low quality = 0–3; moderate quality = 4–6 and high quality = 7–9 (Appendix S2, Texts S1, Figure S1).

2.4 | Data extraction

The following data were extracted from each eligible study on a spreadsheet where possible: author, year, country, continent, study duration, species of animal, origin of sample, diagnostic technique, population size and number of positive samples. Overall, data from 243,864 animals (Sheep: 87,580 and goats: 156,284) from various geographical locations were analysed (Tables 1 and 2).

2.5 | Data analysis

All extracted data were transcribed and stored in a Microsoft Excel spreadsheet. Crude prevalence estimation was done by the number of positive animals divided by the total number of animals sampled

| World region     | No. of study | No. of sheep sampled | No. of positive sheep | Pooled estimate % | 95% CI          | Heterogeneity chi-squared (χ²) | I² | p-value |
|------------------|--------------|----------------------|-----------------------|-------------------|----------------|-------------------------------|----|---------|
| Africa-Asia estimate | 136          | 87,580               | 30,935                | 39.31             | 35.75–42.88 | 67,409.94                     | 99.8 | <.0001  |
| Africa           | 66           | 42,694               | 15,428                | 40.16             | 34.59–45.73 | 45,254.77                     | 99.9 | <.0001  |
| Asia             | 70           | 44,886               | 15,507                | 38.63             | 33.73–43.53 | 21,120.37                     | 99.7 | <.0001  |

Note: No record of goat PPR from other continents.
Abbreviations: CI, confidence interval; I², inverse variance index; χ², Cochran's Q chi-square.

| World region     | No. of study | No. of goat sampled | No. of positive goat | Pooled estimate % | 95% CI          | Heterogeneity chi-squared (χ²) | I² | p-value |
|------------------|--------------|---------------------|----------------------|-------------------|----------------|-------------------------------|----|---------|
| Africa-Asia estimate | 192          | 156,284             | 47,278               | 39.57             | 36.66–42.48 | 63,814.71                     | 99.7 | <.0001  |
| Africa           | 70           | 42,128              | 13,992               | 41.79             | 36.34–47.23 | 45,254.77                     | 99.9 | <.0001  |
| Asia             | 122          | 114,156             | 33,286               | 38.34             | 34.79–41.89 | 20,821.71                     | 99.7 | <.0001  |

Note: No record of goat PPR from other continents.
Abbreviations: CI, confidence interval; I²: inverse variance index; χ², Cochran's Q chi-square.
and expressed as a percentage. Only the crude estimate of prevalence was used throughout, and the 95% confidence interval (CI). The 95% CI of the mean was calculated using the standard formula for a proportion \( p \pm 1.96 \sqrt{\frac{p \times (100-p)}{n}} \), where \( n \) is the studied population size. In the event that the higher limit of CI exceeded 100, then the value was settled to 100 to avoid >100% prevalence, or when the lower limit was lower than the positive value, then the value was settled to 0 to avoid negative prevalence. Data were analysed using the “metan” command of the STATA v.11.0 software (StataCorp LP, College Station, TX, USA). Heterogeneity across studies was assessed by chi-square test on Cochran’s Q statistic (represented as \( \chi^2 \) and \( p \)-values) (Higgins & Thompson, 2002), which was interpreted by \( I^2 \) statistic value, considering the \( I^2 \) values of 25%, 50% and 75% as low, moderate and high heterogeneity respectively (Higgins & Thompson, 2002). Owing to the nature of the studies, there was substantial heterogeneity between studies; therefore, random effect meta-analysis was used for summary statistics. Subgroup analysis was also conducted by world region, age, sex, origin of sample, methods of detection and study duration. Publication bias was assessed by Egger’s test using two funnel plots, and the sources of funnel plots asymmetry were also tested to identify small study effects (Egger, Smith, Schneider, & Minder, 1997).

### 3 | RESULTS

#### 3.1 | Search results and eligible studies

Figure 1 shows the search results. The electronic search on selected search engines identified 1916 articles. After removal of
duplicates and screening of titles and abstracts, a total of 343 eligible articles were found, of which 148 articles were excluded due to following reasons: case report (n = 3); full-text not available (n = 9); individual prevalence data not available (n = 104); experimental trial (n = 12); article in a language other than English (n = 1); retro prospective study (n = 4); same dataset in different publication (n = 2) and others (n = 13). The list of excluded articles together with the causes for their exclusion is provided in Appendix S3, Texts S2. A total of 196 eligible articles were used for systemic review and meta-analysis (Abdalla, Majok, El Malik, & Ali, 2012; Abraham et al., 2005; Abubakar, Ali, & Khan, 2008; Abubakar, Jamal, Arshed, Hussain, & Ali, 2009; Abubakar, Jamal, Hussain, & Ali, 2008; Abubakar, Jamal, Khan, & Ali, 2008; Abubakar, Javed Arshed, Hussain, & Ali, 2011; Abubakar, Manzoor, et al., 2016; Abubakar, Rasool, et al., 2016; Abubakar, Zahur, Afzal, Ali, & Gonzalez, 2017; Abubakar, Zahur, Naeem, Khan, & Qureshi, 2018; Acharya, Poudel, & Acharya, 2018; Adel, Abu-Elzein, Al-Naeem, & Amin, 2004; Adombi et al., 2017; Afera, Hussien, & Amsalu, 2014; Ahmad, Jamal, Ali, & Hussain, 2005; Ahmed et al., 2017; Ahmed, Rahman, Alam, Paul, & Uddin, 2016; Alam et al., 2018; Albayrak & Alkan, 2009; Albayrak & Gür, 2010; Al-Dubaib, 2008, 2009, Ali, Intisar, & Khalfalla, 2014; Al-Majali, Hussain, Aminar, & Majok, 2008; Almeshay et al., 2017; Ameen & Ajayi, 2013; Amin, 2015; Anees et al., 2013; Atta-ur-Rahman, Rahman, Akhtar, & Ullah, 2004; Ayim-Akunnor, Obese, Arthur, Owusu-Ntumy, & Otsyina, 2014; Aytekin, Mamak, Ulucan, & Kalınbacak, 2011; Baazizi, Ait-Oudhia, Parida, Mahapatra, & Khelef, 2015; Baazizi, Khelef, & Hussain, 2017; Balamurugan, et al., 2014; Balamurugan, Saravanan, et al., 2012; Balik, Podder, Samad, & Islam, 2008; Bari et al., 2018; Begum et al., 2016, 2017; Bello et al., 2016, 2018; Bhanuprakash et al., 2008; Bhaskar, Deshmukh, Chopade, Rautmare, & Aziz, 2011; Birindwa, George, Bhikane, Ambore, & Awaz, 2007; Kgotlele, Macha, et al., 2014; Kgotlele, Torsson, Kasanga, Wensman, & Misinzo, 2016; Khan, Siddique, Abubakar, Arshed, & Hussain, 2008; Khan, Siddique, Arshed, Khan, & Rehman, 2007; Khaksheli et al., 2017; Kihu,Gachohi, et al., 2015; Krishna, Rao, & Shaila, 2001; Kumar, Sinha, Roy, Kumari, & Kumar, 2017; Kwiatek et al., 2011; Lawal, Lasisi, Emikpe, & Ogundipe, 2011; Li et al., 2017; Lucky et al., 2016; Lundervold et al., 2004; Luther et al., 2005; Ma et al., 2013; Mangala et al., 2013; Mahajan, Agrawal, Kumar, Mohan, & Pande, 2012, 2013; Mahapatra et al., 2015; Mahmoud, Abdellatif, & Abdalla, 2017; Mahmoud, Abdellatif, & Shazali, 2016; Mahmoud, Elbayoumy, Sedky, & Ahmed, 2017; Mahmoud & Galbat, 2017; Maitlo et al., 2017; Mbuzi, Komba, Kimera, & Kambarage, 2014; Mebratu, Getachew, Tesfaye, Sahu, & Aragaw, 2018; Megersa et al., 2011; Meher, Afrin, Hassan, & Alam, 2017; Mehmood, Ali, Gadahi, Malik, & Shah, 2009; Milind et al., 2018; Mohanto, Hoque, & Juli, 2018; Mostafa, 2012; Moumin, Moussa, Teshale, & Gezahegne, 2018; Muhsen, 2013; Mulindwa et al., 2011; Munir, Shah, Shabbir, & Berg, 2013; Munir, Siddique, Shehzad, Zohari, & Stahl, 2010; Mute et al., 2012; Nabi, Hossain, Saha, Alam, & Giasuddin, 2018; Nath et al., 2014; Naznin et al., 2014; Nizamani et al., 2015; Nwobodo, Ezeifeka, Ezejiofor, & Onyianta, 2013; Opasina, 1985; Opasina & Putt, 1985; Oshiek et al., 2018; Osman, Ibrahim, Osman, Alnour, & Eldin, 2018; Otsyina, Arthur, Ayim-Akunnor, & Obese, 2013; Özkul et al., 2002; Ozmen, Kale, Haligur, & Yavru, 2009; Parvez, Khatun, & Al Noman, 2014; Patil et al., 2009; Poddar, Tuli, Sultana, Akter, & Alauddin, 2018; Raghavendra et al., 2008; Rahman, Alam, Alam, Hasan, & Moonmoon, 2016; Rahman et al., 2018; Rahman, Hassan, Sultana, Uddin, & Hossain, 2017; Rahman, Hossain, Ahsan, Khokon, & Kibria, 2011; Rahman, Shadmim, et al., 2011; Rakshit et al., 2015; Rashid, Asim, & Hussain, 2008; Rony, Rahman, Alam, Dhand, & Ward, 2017; Saeed, Abdel-Aziz, & Gumaa, 2018; Saeed, Ali, Khalafalla, & Rahman-Mahasin, 2010; Sağlam & Temur, 2009; Salih, Elaffid, Saeed, & Ali, 2014; Sande et al., 2011; Sannat, Chandel, Chauhan, & Dadawala, 2011; Saravanan et al., 2007; Saritha, Shobhamani, Rajak, & Sreedevi, 2015; Saritha, Shobhamani, & Sreedevi, 2014; Sarker & Islam, 2011; Şevik & Sait, 2015; Sharma, Mehta, Prakash, & Shukla, 2012; Sharma, Shrivastava, Mehta, & Shukla, 2012; Shukla, Singh, & Hirpurkar, 2008; Siddiqui et al., 2014; Singh, Malik, Sharma, & Kuldeep, 2015; Singh, Saravanan, Sreenivasa, Singh, & Bandyopadhyay, 2004; Singh, Jindal, Nain, & Khokhar, 2006; Soltan & Abd-Eldaim, 2014; Sundufu et al., 2015; Swai et al., 2009; Taylor, Al Busaidy, & Barrett, 1990; Thombare & Sinha, 2009; Torsson et al., 2017; Undrakhbayar, Uuganbayar, & Odblegel, 2016; Wang et al., 2009; Waret-Szkuta et al., 2008; Yapici et al., 2014; Yener, Sağlam,
3.2 | Continents and countries

All articles included in this study represent data from two continents (Africa and Asia), covering 34 countries of the world. The highest number of articles (n = 129) were from Asia covering 12 countries: Bangladesh (n = 37), China (n = 2), India (n = 38), Iraq (n = 1), Kazakhstan (n = 1), Kyrgyzstan (n = 1), Mongolia (n = 1), Nepal (n = 1), Oman (n = 1), Pakistan (n = 28), Saudi Arabia (n = 7) and Turkey (n = 11). Articles (n = 67) from Africa covered 22 countries: Algeria (n = 3), Benin (n = 1), Chad (n = 1), Comoros (n = 1), Congo (n = 1), Djibouti (n = 1), Egypt (n = 4), Eritrea (n = 1), Ethiopia (n = 10), Gabon (n = 1), Gambia (n = 1), Ghana (n = 2), Jordan (n = 1), Kenya (n = 1), Libya (n = 1), Morocco (n = 1), Niger (n = 1), Nigeria (n = 11), Sierra Leone (n = 1), Sudan (n = 13), Tanzania (n = 8) and Uganda (n = 2).

### Table 3: Pooled prevalences and estimated sources of heterogeneity in the prevalence of PPR in sheep and goats

| Variables                | Population | Pooled estimate prevalence (%) | 95% CI            | Heterogeneity chi-squared (χ²) | I²% | p-value   |
|--------------------------|------------|---------------------------------|-------------------|-------------------------------|-----|-----------|
| World region             |            |                                 |                   |                               |     |           |
| Africa-Asia estimate     | 243,864    | 39.46                           | 37.23–41.69       | 130,000                       | 99.8| <.0001    |
| Africa                   | 84,822     | 40.99                           | 37.20–44.79       | 68,670.75                     | 99.8| <.0001    |
| Asia                     | 159,042    | 38.43                           | 35.64–41.22       | 64,331.34                     | 99.7| <.0001    |
| Age                      |            |                                 |                   |                               |     |           |
| Young (≤1 year)          | 25,059     | 35.99                           | 31.12–40.87       | 6,235.86                      | 99.3| <.0001    |
| Adult (>1 year)          | 26,879     | 39.91                           | 33.70–46.12       | 10,675.58                     | 99.5| <.0001    |
| Sex                      |            |                                 |                   |                               |     |           |
| Male                     | 11,171     | 35.14                           | 30.28–40.01       | 1929.90                       | 97.5| <.0001    |
| Female                   | 23,168     | 41.00                           | 35.09–46.91       | 5,307.65                      | 99.1| <.0001    |
| Origin of sample         |            |                                 |                   |                               |     |           |
| Abattoir                 | 2,192      | 42.72                           | 37.97–47.47       | 16.86                         | 70.3| <.0001    |
| Farm                     | 25,305     | 42.70                           | 36.40–49.01       | 16,225.88                     | 99.7| <.0001    |
| Free range flocks        | 9,488      | 39.33                           | 32.32–46.34       | 5,827.96                      | 99.4| <.0001    |
| Hospital                 | 42,123     | 30.15                           | 26.95–33.36       | 7,532.16                      | 99.5| <.0001    |
| House hold flocks        | 19,204     | 37.38                           | 32.22–46.53       | 24,957.71                     | 99.8| <.0001    |
| Mixed flocks             | 83,976     | 40.76                           | 36.43–45.09       | 15,715.13                     | 99.5| <.0001    |
| Methods of detection     |            |                                 |                   |                               |     |           |
| IHC                      | 362        | 32.32                           | 7.76–56.87        | 49.15                         | 95.9| <.0001    |
| PCR                      | 2,453      | 48.03                           | 36.32–59.74       | 1,476.29                      | 98.0| <.0001    |
| Serology                 | 163,886    | 40.13                           | 37.45–42.81       | 84,175.68                     | 99.7| <.0001    |
| Symptomatic              | 77,163     | 33.30                           | 28.06–38.55       | 45,212.97                     | 99.9| <.0001    |
| Study duration           |            |                                 |                   |                               |     |           |
| ≤6                       | 38,327     | 41.47                           | 36.09–46.85       | 31,834.92                     | 99.7| <.0001    |
| >6 to ≤12                | 74,100     | 31.39                           | 28.37–34.42       | 16,186.05                     | 99.6| <.0001    |
| >12                      | 97,644     | 38.64                           | 35.92–45.07       | 63,650.34                     | 99.6| <.0001    |

Abbreviations: CI, confidence interval; I²: inverse variance index; χ², Cochran’s Q chi-square.
prevalence of PPR in goats ranged from 38.34 (95% CI: 34.79%–41.89%) to 41.79 (95% CI: 36.34%–47.23%), with an overall random pooled prevalence of 39.57 (95% CI: 36.66%–42.48%) with considerable heterogeneity ($I^2 = 99.7\%, p < .0001$) (Table 2). Overall, the Africa-Asia pooled estimated prevalence of PPR in sheep and goats was 39.46% (95% CI: 37.23%–41.69%) with substantial heterogeneity ($I^2 = 99.8\%, p < .0001$) (Table 3). The estimated pooled prevalence of PPR in sheep and goats by country is shown in Figure 2 and Table 4. The pooled prevalence of PPR in sheep and goats by publication year is presented in Figure 3.

Figures 4–7 show the prevalence estimates from individual contributing studies by world region. Country-wise subgroup analysis showed that the lowest prevalence was reported as 0.59% (95% CI: 0.07%–1.11%, $\chi^2$: 0.08, $I^2 = 0.0\%, p < .774$) in Kazakhstan and the highest prevalence as 84.15% (95% CI: 70.17%–98.13%; $\chi^2$: 0.01, $I^2 = 0.0\%, p < .931$) in Benin. Age-wise subgroup analysis showed that the prevalence estimate in young sheep was 41.49% (95% CI: 29.47%–53.50%; $\chi^2$: 1718.98, $I^2 = 99.2\%, p < .0001$) and in young goats was 33.44% (95% CI: 27.84%–39.04%; $\chi^2$: 4,367.58, $I^2 = 99.3\%, p < .0001$), while the prevalence estimate in adult sheep was 48.40% (95% CI: 36.21%–60.60%; $\chi^2$: 2,125.88, $I^2 = 99.3\%, p < .0001$) and in adult goat was 35.91% (95% CI: 28.47%–43.35%; $\chi^2$: 8,235.89, $I^2 = 99.6\%, p < .0001$). Sex-wise subgroup analysis showed that the prevalence estimate in male sheep was 35.09 (95% CI: 25.65%–44.54%; $\chi^2$: 305.95, $I^2 = 96.1\%, p < .0001$) and male goats was 35.22% (95% CI: 29.19%–41.25%; $\chi^2$: 1607.66, $I^2 = 97.8\%, p < .0001$), while the prevalence estimate in female sheep was 40.55 (30.11%–51.00%; $\chi^2$: 806.63, $I^2 = 98.5\%, p < .0001$) and in female goats was 41.18 (34.07%–48.29%; $\chi^2$: 4,195.33, $I^2 = 99.2\%, p < .0001$).

Pooled prevalences based on age, sex, origin of samples, methods of detection and study duration are shown in Table 3. The overall estimated pooled prevalence of PPR in sheep and goats slaughtered in abattoirs was 42.72% (95% CI: 37.97%–47.47%) while the prevalence in hospital-based studied animals was 30.15% (95% CI: 26.95%–33.36%). Prevalence estimates were 48.03% (95% CI: 36.32%–59.74%) in studies that used PCR and 32.32% (95% CI: 7.76%–56.87%) in studies that used immunohistochemistry to detect PPR in sheep and goats. Studies conducted for less than or equal to 6 months had higher prevalence, at 41.47% (95% CI: 36.09%–46.85%), than those conducted for more than 12 months [38.64% (95% CI: 35.92%–45.07%)] and for between 6 and 12 months [31.39% (95% CI: 28.37%–34.42%)].

3.4 | Source of heterogeneity

Heterogeneity in the prevalence of PPR in sheep and goats was due to six sources: world region ($p < .0001$), age ($p < .0001$), sex ($p < .0001$), origin of the sample ($p < .0001$), method of detection ($p < .0001$) and study duration ($p < .0001$). Overall, there was substantial heterogeneity ($I^2 > 80\%$) in most pooled prevalence estimates (Table 3).

The extent of publication bias in the included articles was measured separately for sheep and goats. Funnel plots indicated that there was publication bias (Figure 8). Egger’s test for publication bias also showed that there was a small study effect. The estimated bias coefficient in sheep was 4.28 (95% CI: 4.18–4.37) with a standard error of 0.049 providing a $p$-value of <.0001, while the estimated bias coefficient in goats was 4.09 (95% CI: 3.98–4.20) with a standard error of 0.054 and a $p$-value of <.0001. An assessment checklist for possible bias and scores of individual studies is supplied (Appendix S2, Table S2).

4 | DISCUSSION

This systemic review and meta-analysis summarises the prevalence of PPR in sheep and goats at regional level, based on a large population ($n = 243,864$). Articles included were from 34 countries from two continents, which allowed the analysis of reliable prevalence...
estimates, to increase knowledge of PPR epidemiology and consequently inform PPR control and eradication. This is the first meta-analysis of the prevalence of PPR in sheep and goats at a regional level to the best of the author’s knowledge.

The analysis showed a high prevalence of PPR in sheep and goats in most endemic countries of Africa and Asia, with an estimated pooled prevalence of 39.46% (95% CI: 37.23%–41.69%) across 196 published studies. Although countries of Africa and Asia had the highest reported disease prevalence, it has recently been reported that PPR is emerging in ruminant populations in Europe (Parida et al., 2016). However, because of a lack of individual-level prevalence data or studies being in species other than sheep and goat, studies from Europe were not included in this meta-analysis.

Africa had a higher disease prevalence than Asia. Most of the individual studies showed a high prevalence; however prevalence estimates were low in only a few studies (Ameen & Ajayi, 2013; Cêtre-Sossah et al., 2016; Ezeokoli et al., 1986). Reasons for the high prevalence of PPR in sheep and goats could include transboundary movement of infected animals with inadequate quarantine, the presence of hot and humid climatic conditions that favour disease epidemiology, lack of vaccination or vaccine administration monitoring, lack [TABLE 4]  Estimated pooled prevalence of PPR in sheep and goats in different countries

| Country       | Population | Pooled estimate prevalence (%) | 95% CI        | Heterogeneity (\(\chi^2\)) | \(I^2\)% | p-value |
|---------------|------------|---------------------------------|---------------|----------------------------|---------|--------|
| Algeria       | 7,440      | 19.29                           | 15.62–22.96   | 93.41                      | 90.4    | .0001  |
| Bangladesh    | 41,418     | 31.02                           | 26.60–35.45   | 7,945.5                    | 99.5    | .0001  |
| Benin         | 19         | 84.15                           | 70.17–98.13   | 0.01                       | 0       | .931   |
| Chad          | 3,546      | 52.73                           | 44.10–61.35   | 27.68                      | 96.4    | .0001  |
| China         | 1632       | 42.93                           | 0–88.72       | 1503.58                    | 99.9    | .0001  |
| Comoros       | 1,048      | 2.37                            | 1.43–3.31     | 0                          | –       | –      |
| Congo         | 150        | 64.67                           | 57.02–72.32   | 0                          | –       | –      |
| Djibouti      | 1,516      | 4.79                            | 0.70–8.87     | 12.58                      | 92      | .0001  |
| Egypt         | 2,776      | 53.26                           | 38.82–67.71   | 650.49                     | 98.6    | .0001  |
| Eritrea       | 32         | 44.19                           | 15.23–73.15   | 1.83                       | 45.3    | .176   |
| Ethiopia      | 16,958     | 25.6                            | 21.56–29.65   | 4,404.54                   | 99.5    | .0001  |
| Gabon         | 106        | 59.22                           | 0–100         | 59.3                       | 98.3    | .0001  |
| Gambia        | 1,686      | 44.1                            | 33.80–54.40   | 14.53                      | 93.1    | .0001  |
| Ghana         | 3,269      | 69.97                           | 47.13–92.82   | 528.46                     | 99.4    | .0001  |
| India         | 43,838     | 39.7                            | 33.73–45.68   | 15,824.5                   | 99.6    | .0001  |
| Iraq          | 1,175      | 27.66                           | 25.10–30.22   | 0                          | –       | –      |
| Jordan        | 1,329      | 38.93                           | 19.39–58.47   | 46.94                      | 97.9    | .0001  |
| Kazakhstan    | 679        | 0.59                            | 0.07–1.11     | 0.08                       | 0       | .774   |
| Kenya         | 969        | 35.7                            | 27.63–43.76   | 7.16                       | 86      | .007   |
| Kyrgyzstan    | 655        | 35.11                           | 31.46–38.77   | 0                          | –       | –      |
| Libya         | 721        | 51.18                           | 36.60–65.75   | 9.17                       | 89.1    | .002   |
| Mongolia      | 1,950      | 0.81                            | 0.41–1.21     | 0.18                       | 0       | .674   |
| Morocco       | 36         | 44.44                           | 28.21–60.68   | 0                          | –       | –      |
| Nepal         | 460        | 82.61                           | 79.15–86.08   | 0                          | –       | –      |
| Niger         | 519        | 44.45                           | 38.70–50.21   | 1.82                       | 45      | .178   |
| Nigeria       | 12,950     | 39.29                           | 28.75–49.83   | 14,974.08                  | 99.9    | .0001  |
| Oman          | 724        | 24.31                           | 21.18–27.43   | 0.04                       | 0       | .846   |
| Pakistan      | 56,984     | 43.55                           | 38.22–48.88   | 8,936.32                   | 99.5    | .0001  |
| Saudi Arabia  | 6,743      | 49.97                           | 34.32–65.62   | 5,976.52                   | 99.8    | .0001  |
| Sierra Leone  | 5,679      | 29.04                           | 27.86–30.22   | 0                          | –       | –      |
| Sudan         | 16,832     | 53.97                           | 46.45–61.49   | 1,890.76                   | 98.8    | .0001  |
| Tanzania      | 6,487      | 38.97                           | 32.20–45.73   | 257.96                     | 95.7    | .0001  |
| Turkey        | 2,784      | 34.29                           | 25.15–43.43   | 342.16                     | 96.2    | .0001  |
| Uganda        | 754        | 26.06                           | 0–54–25       | 194.05                     | 99      | .0001  |

Note: Not estimated due to having single study.
Ahaduzzaman, of awareness about PPR among backyard farmers, and limited funding for disease eradication in developing or underdeveloped countries. Moreover, many studies included in this meta-analysis used serum sample or symptomatic diagnostic approaches to report PPR prevalence; such approaches can quickly reveal the status of a large population (Delil et al., 2012; El-Rahim et al., 2010; Mahamat et al., 2018; Parvez et al., 2014).

The estimated pooled prevalence indicated that PPR is equally prevalent in both sheep and goats. Prevalence was higher in goats than sheep, but the difference was not statistically significant.

![Figure 3](image)

**Figure 3** Trend in the pooled prevalence (LSM ± SE) of Peste des petits ruminants (PPR) in sheep and goats based on 196 studies within the range of this meta-analysis (1969 to 2018) \( (p = 0.0003) \). No prevalence data found between 1969 and 1984.

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![Figure 4](image)

**Figure 4** Forest plot of the prevalence estimates of Peste des petits ruminants (PPR) in sheep amongst studies conducted in Africa.
Such findings are consistent with other research that reported an equal prevalence of PPR in sheep and goats (Balamurugan, Saravanan, et al., 2012). Several individual studies reported that PPR is more prevalent in sheep than goats (Abubakar et al., 2009; El-Yuguda et al., 2010; Enan et al., 2013) or more prevalent in goats than sheep (Delil et al., 2012; Farougou et al., 2013; Fentie et al., 2018). Although there are biological differences between sheep and goats, higher prevalence in one

![Forest plot of the prevalence estimates of Peste des petits ruminants (PPR) in goats amongst studies conducted in Africa](image)

**FIGURE 5**

Forest plot of the prevalence estimates of Peste des petits ruminants (PPR) in goats amongst studies conducted in Africa
species than another could be due to factors such as sampling process, richness or distribution of animal in a geographical area, management practices and strain of the virus. It is also possible that PPRV preferentially infects goats over sheep or vice-versa, depending on the endemic situation, and disease severity may also vary between species (Truong et al., 2014). PPR was higher in adult animals than in young animals based on estimated pooled prevalence. These results agree with the
findings of many studies (Abubakar et al., 2009, 2011, 2017; Acharya et al., 2018; Gari et al., 2017), but not with several others (Alam et al., 2018; Bari et al., 2018; Bello et al., 2018). The higher prevalence in adults could be due to factors such as the higher likelihood of older animals being exposed to PPRV because of virus circulation, the foraging behaviour of adult animals and the decay of maternally derived
antibody in older animals. It has been reported that PPRV is highly immunogenic, and animals remain seropositive for a long period, particularly in an endemic area (Acharya et al., 2018; Balamurugan, Sen, et al., 2012). In contrast, higher prevalence in young animals could be due to malnutrition, less developed immune system and poor husbandry practices (Bari et al., 2018).

The estimated pooled prevalence of PPR was higher in female animals than in male animals. This could be due to breeding females being used for flock reproduction maintenance for a more extended period than males, while males are sold for meat at an early age (1–2 years) except those used for breeding purpose. Other factors could be a higher density of females than males in flocks, or physiological differences between females and males (e.g. females face some degree of stress as a result of production and reproduction).

The findings of this study are in agreement with previous findings (El-Yuguda et al., 2013; Farougou et al., 2013; Mahamat et al., 2018). Other studies found a higher prevalence in males, possibly due to a higher proportion of male animals in a flock particularly when the age of the studied animals was under two years (Rony et al., 2017). The variation in the prevalence data in this report also depended on the source of the sample, the method of detection and the length of the study. Prevalence was higher in animals originating from abattoirs and farms, and in animals kept in mixed flocks. This may be due to there being a higher chance of having sick animals in abattoirs (because many farmers sell animals for slaughter during outbreaks) or to animals in abattoir coming from different regions and different farms; alternatively, it may be due to the method of detection in case of mixed flocks and farm-based studies, given that most of
the studies were conducted using serology (Goossens et al., 1998; Rashid et al., 2008). Cross-transmission of PPRV between sheep and goats, or persistence of the virus in mixed flocks could be another contributing factor (Gari et al., 2017). Based on the method of detection, the prevalence was higher where the PCR-based method was used; this is due to PCR being more sensitive than other methods. Studies conducted for less than six months showed a higher prevalence, and this could be due to a difference in study design. Egger’s test results using a linear regression approach and funnel plots asymmetry revealed strong evidence of publication bias. However, the source of funnel plot asymmetry could additionally be due to true heterogeneity, location, data irregularity and artefacts or even to chance (Egger et al., 1997).

4.1 | Limitations

This study has several limitations. First, no reports on PPR prevalence in sheep and goats were found in continents other than Africa and Asia within the search range. Thus, it was not possible to obtain information on the prevalence from these regions. Second, age is an important factor to PPR, but there were not enough articles on age available for inclusion to carry out a multiple subgroup analysis; hence, the data are presented as young and adult. Third, the review excluded non-English articles, unpublished articles, retrospective articles, method validation articles, results of experimental trials and case reports. Fourth, the genotype/sequencing data used to identify countries that are endemic for PPR or have PPR outbreaks (e.g. Bulgaria) have shown that PPRV is prevalent in many countries of the world, but it was not possible to include them in this study because of the lack of prevalence data. Finally, heterogeneity in models was significant, suggesting that other factors that were not considered might have had substantial effects.

5 | CONCLUSIONS

The Africa–Asia pooled prevalence of PPR in sheep and goats estimated through this meta-analysis was high, and it varied between geographical regions and countries. The disease was found to be more prevalent in Africa than in Asia, and more prevalent in adult animals; thus, vaccination of young animals may prevent the disease. The findings suggest that screening tests for PPR, and effective preventive and eradication measures, should be routinely carried out in sheep and goat flocks in regions with a high disease prevalence, to control the outbreak and improve animal productivity. Further, there are regions where the virus is circulating, but no reports on prevalence estimates are available; therefore, epidemiological surveillance is needed for estimating disease status and eliminating the disease. Additionally, factors that contribute to the prevalence estimate heterogeneity should be handled appropriately in any survey to accurately estimate the true extent of PPR.

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CONFLICT OF INTEREST

The author declares that he has no competing interests.

AUTHOR CONTRIBUTION

Md Ahaduzzaman: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Visualization; Writing–original draft; Writing–review & editing.

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**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section.

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