Analysis of spatial and temporal risk of Peste des Petits Ruminants Virus (PPRV) outbreaks in endemic settings: A scoping review

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Abstract

Surveillance shows that Peste des petits ruminants (PPR) is endemic in both Africa and Asia due to its continuous circulation. Several epidemiological factors work together to support PPR's geographical spread. To investigate the risk of PPR transmission, analytical techniques based on spatial, spatiotemporal, and transmission dynamics have been employed. The risk factors linked to the spatiotemporal distribution and transmission dynamics of PPR at the regional level are extremely poorly understood. This study assessed the risks of Peste des Petit ruminant virus (PPRV) epidemics during a comprehensive evaluation of peer-reviewed literature, highlighting the differences between geographical and spatial-temporal techniques used in endemic zones. Utilizing the PubMed and Google Scholar databases, a scoping literature analysis of PPR research papers that evaluated PPR risks in endemic areas using spatial and spatiotemporal techniques was conducted. Eight papers with a global perspective were chosen from 42, 20 of which were on Asia, and 14 on Africa. 35.7% employed spatial autocorrelation, while 61.9% used clustering analysis. Of the research, the majority (71.2%) described temporal trends, whereas 13 publications (30%) used modelling methodologies. Geographic accessibility (n = 19), trade and commerce (n = 17), environment and ecology (n = 12), socioeconomic variables (n = 9), and demography and livestock–wildlife interactions (n = 20) are the five risk factors that were assessed. All the risk factors were related, however only two papers discussed the transmission dynamics of PPR. Our understanding of PPR outbreaks in endemic environments has improved because of the review, which also encourages evidence-based decision-making to lessen the virus's effects on small ruminant populations. It has been demonstrated that the association of additional risk variables with livestock trade, the primary force behind livestock migration, significantly increases the probability of PPR outbreaks in endemic areas. Since many studies are conducted in Asia rather than Africa, Africa should be considered in future prediction model development to evaluate possible eradication strategies at the national and regional levels.

Keywords: Peste des petit ruminant (PPR) epidemics, spatial methods, spatiotemporal methods, risk factors

1. Context

A virus known as peste des petits ruminants (PPR) affects small ruminants, primarily sheep and goats, but it can also infect other domestic animals (1). The PPR virus (PPRV) is a single-strand, non-segmented RNA virus of the genus Morbillivirus in the family *Paramyxoviridae* (2). PPRV's genome spans 15,948 nucleotides (nt) and is structured into six open reading frames (ORFs). The six structural proteins that are encoded by these ORFs are the polymerase (P) or large protein (L), fusion protein (F), phosphoprotein (P), matrix protein (M), hemagglutinin protein (H), and nucleoprotein (N). Additionally, the non-structural proteins C and V are encoded by the ORF transcription unit (3). Four lineages have been described from two structural proteins N or F by phylogenetic studies using partial gene sequences (3). These lineages of PPRV are distributed in several geographical areas including Africa, Asia and Europe (4). All four PPRV lineages are present in Africa, where lineage I viruses have been confined in West African countries since 1940. Lineage II is predominantly present in West Africa, although it has recently been reported in the Democratic Republic of the Congo (DRC) and Tanzania (5). Although Lineage III is prevalent throughout northeastern, eastern, and central Africa as well as the Comoros islands, it has not been seen in the north or west of the continent (5). To date, PPR has been identified in the northern, western, central and eastern regions of Africa and is gradually moving southwards. Hundreds of millions of domestic small ruminants and wildlife are at risk of infection as the PPRV continues to spread across previously uninfected regions (6). However, the PPRV infection that has been found in previously uninfected areas and the admixture of lineages in countries that have been infected jointly emphasize the geographically and temporally dynamic character of PPR (7). With annual global economic losses estimated at approximately $1.45 and 2.1 billion USD, half of these losses impact Africa, and a quarter affect Asia. Like other livestock respiratory diseases losses are caused by mortality, which reaches up to 20% in naive population and morbidity, which reaches up to 100% (8,9). A global program to eradicate PPR by 2030 has been formally launched by the Food and Agriculture Organization (FAO) and the World Organization for Animal Health (WOAH), formerly known as OIE), due to the high impact PPR on sheep and goat farmers (10). Global PPR eradication campaigns adopt spatial and spatiotemporal risk analysis models for disease prevention, focusing on PPR risk factors and disease transmission dynamics in livestock contacts (11). Network analysis, prediction, and simulation models can be used to identify PPR clusters and their drivers, providing crucial information for disease investigation (12). Enormous availability of such information could support the development of locally adapted control and surveillance strategies (13). Combining such risk factor information with genetic and mobility network data may make it possible to identify disease hot spots, which are crucial for virus entry and dissemination to various regions (13). Identification of PPR hotspots will involve the use of spatial and Spatiotemporal tools to analyze PPR epidemic data. Such analysis will also explore the patterns and risk factors of the disease (14). Nevertheless, a variety of spatiotemporal tools are accessible for evaluating a range of spatiotemporal hypotheses to meet distinct goals. Either in testing a hypothesis, the outcomes of such a study can be directly compared if the analytical methods used are well understood (15). For instance, studies examining how local elements like topography, socioeconomics, demography, and environment can impact disease reporting, identification, and circulation changes over time and space (16). The important step in choosing a model's parameters is to consider the disease pathway that is thought to connect epidemiological factors with epidemics (15). In this aspect, disease transmission dynamics are contextualized to a specific location where the contact network is factored in disease diffusion to various areas. The need for this review remains critical because of the overall knowledge gap on the effectiveness of these tools in the analysis of PPR control in endemic situations (16). To our knowledge, no studies have reviewed the spatial and spatio-temporal methodologies used in PPR research. A narrative review by (17) summarizes the occurrence and distribution of PPR in Tanzania. In addition to estimating the prevalence of PPR in sheep and goats, systematic review publications assess probable contributing factors to the disease's heterogeneity in prevalence and distribution (4). The only Scoping review conducted by (18) was on PPR diagnostic platforms. Prior reviews did not discuss models, variables, spatial, and spatiotemporal methodological frameworks for PPR risks, leading to a high lack of information on risks-based spatial and spatiotemporal analysis (19). By filling this gap, PPR can be controlled and eventually eradicated. This study evaluates spatial and spatial-temporal methodological approaches in Peste des petit ruminant (PPR) epidemics, aiming to identify priority research areas, suggest interventions, and standardize modelling inputs for improved comparability.

2. Data acquisition

2.1. Protocol

In compliance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) standards, a scoping literature review was carried out. (Sup. Table 1), in which a checklist for scoping reviews was adopted (20). The approach suggested by Arksey & O'Malley was followed in this study, which included formulating the research question, finding pertinent sources, choosing references, charting the data, compiling, summarizing, and reporting the findings (20) (Figure 1).

2.2. Research Questions Identification

The research questions listed below were the main focus of the scoping review.:

(a) What techniques have been applied to investigate PPRV's spatiotemporal and spatial distribution in endemic environments?

(b) Based on the examination of those occurrences, what is known regarding PPR risk from the literature (e.g., Finding clusters, hotspots, or seasonal or temporal tendencies)?

(c) Which risk variables have been examined and linked to PPR prevalence in endemic areas in Asia and Africa?

(d) How do the risk factors under investigation affect the dynamics of PPRV transmission?

2.3. Search strategy and selection criteria

Spatial and spatial-temporal analysis served as the basis for a scoping evaluation of the PPRV threats. Risk factors in endemic areas were discovered with the assistance of a library professional for electronic bibliographic search, and the search strategy comprised a set of keywords on spatial and spatiotemporal techniques. Two computerized bibliographic databases were systematically searched to find peer-reviewed original publications published in English-language journals between January 1993 and June

2024. The peer-reviewed publications that were part of this review were found using the Google Scholar and MEDLINE (PubMed) search engines. Boolean operators were used to select the papers based on phrases like "pest des petit ruminant virus (PPRV) AND risks AND spatial and spatial-temporal analysis AND epidemics AND endemic countries." In order to get results, essential terms were trimmed down during the PubMed search. 766 documents were found overall through the searches of the two electronic databases (Google Scholar: 648, and PubMed: 118, as shown in Figure 2).

2.4. Eligibility criteria

PPR research using spatial, temporal, or spatiotemporal techniques for data analysis and inference was considered in this scoping review. Studies on various spatiotemporal analytical tools can be employed for epidemiological research based on the classification put forward by (21). These can be categorized according to the analysis's goals for (a) description and visualization, (b) pattern identification and geographical or spatiotemporal dependence, (c) spatial smoothing and interpolation, and (d) modelling and regression research. We were especially interested in research that included putative PPR risk factors to forecast illness occurrence or that looked at epidemiological parameters associated with PPR outbreaks at the population level within the modelling and regression category. All publications with original peer-reviewed articles were chosen in order to meet the inclusion requirements. Based on data from the most recent WOAH list of members and areas designated as PPR-free (Resolution No. 17 (89th General Session, May 2022), PPR endemicity was determined. However, research carried out in nations with recognized free zones or PPR-free certifications, like Russia, was eligible for inclusion (22). Consequently, research that (a) used data from population outbreaks in PPRV-endemic nations; (b) reported patterns or distributions of PPR epidemics; or (c) used data that was geographically or temporally connected to model PPR risk; (c) were published in an English-language peer-reviewed scientific publication between January 1990 and July 2024; and (d) confirmed cases of PPR in wildlife and livestock (such as cattle, small ruminants, and camels) were taken into account for inclusion.

Exclusion criteria

Excluded were studies that used data from farm epidemic surveys that included risk factors and self-reported PPR occurrences. Furthermore, this synthesis excluded studies that were meant to be risk assessments, epidemic investigations, or narrative literature reviews that reported PPR occurrence and trends (without further data analysis). Studies from nations that are known to be PPR-free, with or without immunization, were not included in the review, as Figure 1 illustrates.

2.5. Selection of relevant and reliable studies

To balance sensitivity and specificity in research, a search method was created utilizing electronic databases, Boolean, and proximity operators. Titles and abstracts were used to filter reports, removing duplicates and irrelevant papers. Reasons for exclusion were noted, and full texts were obtained for inclusion. Articles were examined for selection by two reviewers with expertise in molecular epidemiology and PPR surveillance. Conflicts that arose during the screening process were settled.

Figure 1: PPR status depending on the acknowledgement of WOAH PPR. The grey areas are either unregistered PPR status, endemic, or reported occasional incidents.

2.6. Data extraction from included studies

Every study's data was extracted by a single reviewer using a pre-made, standardized form in a Microsoft Excel Spreadsheet that contained the following:

(a) Study attributes include author, publication year, years examined, nation, geographic reach, and species.

(b) PPR epidemic information and diagnosis, including the surveillance system, data source, and diagnostic criteria; (c) The type of analytical tool used, the process for grouping and identifying patterns in the data, the method for assessing the data based on time and season, and the list of epidemiological factors that were investigated and their outcomes. JJM and JNH extracted and validated data from papers, analyzing them for accuracy and quality appraisal. Spatial distribution, cattle commerce, weather, climate change, and species/age/sex were among the topics found through thematic analysis.

2.7. Collating, summarizing and reporting the findings

The sizes and data formats suggested by (15) were used to categorise the methods for formally evaluating the existence of clusters. As previously mentioned by (21) the framework was adapted to categorise analytical tools for spatial or spatial-temporal analysis according to their function. Using five primary categories, epidemiological models examine the variables that affect PPRV introduction, transmission, survival, and the efficacy of control strategies. spatial accessibility; (b) the demography of livestock and the interactions between livestock and wildlife; (c) the trade in livestock; (d) socioeconomic considerations; and (e) ecology and environment. The term "other factors" was used to group epidemiological covariates that did not fall into any of the categories (Sup. Table 2) and Figure 4). By merging essential elements and presenting data narratively, the review investigates the relationship between epidemiological determinants and PPR epidemics. R version 4.3.3 (*ggplot2, webr, tidyr*, and *dplyr*) was used for the analyses (23).

3. Results

3.1. General characteristics of the selected studies

A total of 42 studies for the quantitative synthesis and 57 papers for the qualitative synthesis were included using the electronic search approach. Out of the original pool of approximately 766 publications that were screened, 101 were examined in full text, and 57 of those were removed due to their inability to meet the eligibility requirements. requirements (Figure 2).

Figure 2: Flowchart showing the study records' bibliographic search and eventual inclusion in the review

3.2. Time intervals and geographic regions

In Africa and Asia, the distribution of studies by geographic scale and scope differed (Figure 3). Included research in Figure 3 spans 21 nations spread across two continents (Africa and Asia). Most research was carried out on a national level using PPR pandemic data from official sources (95%), which covered the entire country (45%). PPR epidemics were frequently identified based solely on clinical presentation in most studies, where data were gathered as part of passive monitoring systems (37.5%) (Sup. Table 2). Studies differed in the cattle species for which outbreaks were documented and the spatial unit employed for analysis (Sup. Table 2). Epidemic reports from sheep and goats were included in certain research (50%, n = 20). Nevertheless, PPR epidemics in other species categories were examined in 2.5–5% of the investigations that were documented. Several studies looked at long-term epidemic data, the longest of which was a 44-year PPR outbreak case series from India (24). Eleven studies looked at epidemic data collected during a ten-year period, however, the length of each study varied (median = 3 years; range: 1–44). Although a number of papers included a range of analytical tools and objectives, the majority of studies concentrated on the description and visualization of epidemics.

Figure 3: Geographical distribution of the papers that were part of the scoping review.

Figure 4: Classification of risk variables for outbreaks of Peste des petits ruminants using conceptual frameworks.

3.3. Methods used to identify spatial and temporal variations of PPRV risk factors

Error! Reference source not found. shows various spatial, temporal and Spatiotemporal methods that were used to visualize patterns, explore spatial clusters, and model risks across space and time. Although the results of some studies suggested the use of these techniques, they did not state clearly how useful they were. Over half of the studies used spatial clustering analysis techniques to test the non-randomness hypothesis of PPR epidemic distribution. 35.7% and 26.2% used spatial or spatial-temporal tools. Four studies used various approaches for identifying clusters in parallel, including Moran's I, Maximum entropy spatial statistic, Getis-Ord, and Clark Evans test. SaTScan was used for simultaneous cluster detection (11). In three studies, the direction of PPR epidemic progression was determined using spatiotemporal directionality tests.

Figure 5: Dimensions and data forms for classification of cluster analysis modified from

3.4. Spatial autocorrelation or spatial clustering

Of the investigations, 35.7% (n = 15) showed evidence of using PPR spatial autocorrelation approaches for illness cluster identification. However, because different methods were employed to find these clusters (unusual aggregation of epidemics) and hotspots (excess level of epidemics compared to a threshold level), the data configuration on these findings tended to differ both within and between studies (16). Heterogeneous results were reported by four research, which noted the discovery of random or clustered patterns that differed depending on the time period or analytical technique. For instance, (25–27) found that the identification of spatial association was impacted by annual change. The subsequent two investigations (11,28) found random spatial patterns and clustering tendencies that changed over time, as well as the different clustering techniques applied in the research. Sup. Table 5 summarizes the cluster evaluation techniques and overall results of the assessed research. Possibly as a result of local disease status, tool modifications, hypothesis testing, and assumptions made, cluster size, as indicated by significant radius, varies greatly between research.

3.5. Temporal and seasonal trends assessment

Depending on the underlying data's temporal aggregation, the majority of research (71.2%, n = 30) detailed the temporal patterns of PPR outbreaks aggregated each day, week, month, or year. The model known as the Generalized Linear Negative Binomial Regression, (11), Generalized Linear Mixed Models (GLMMs) (29), Negative Binomial (27), linear (13,24,30,31) or logistic regression models (32) Were used to explore or test hypotheses related to temporal trends. Other studies resorted to Bayesian approaches (2,3,33). The NAADSM (North American Animal Disease Spread Model (12,34), autoregressive integrated moving average model (ARIMA) (35), Least Cost Path (LCP) (36), Random forest (26) Ensemble Algorithm (37), Event-Driven Memoryless model of state transitions (38), Regression Tree Models (26) and Mantel Correlograms (13), which were employed to investigate the relationship between genetic distances and various measures of network and geographic distance. Moreover, 4 studies formally analyzed PPR seasonality through the assessment of seasonal trends distributed geographically and socioeconomically (1,22,24,25).

3.6. Modelling approaches

A variety of geographical and spatial-temporal tools were used to evaluate the relationship between a number of epidemiological parameters and PPR epidemics, as well as to describe the patterns of PPR epidemic distribution and identify disease hotspots using clustering approaches. Thirteen (30.9%) of the research in this study used covariables to forecast PPR risk, create risk probability maps, or investigate the relationship between population-level epidemiological factors and the outbreaks. Eleven research modelled or projected PPR counts (19%, n = 8) using epidemiological parameters (11,14,27,33,35–37,39–41)**.** Six studies focused only on predicting PPR epidemics using epidemiological factors as covariates to forecast the PPRV suitability area and estimate the spatial risk (number of outbreaks in PPR passive surveillance data (25–27,37,42,43). Transmission dynamics were also evaluated using metapopulation model (33). Before applying statistical models to evaluate the risks of the PPR epidemic, visualization and descriptions of numerous PPR epidemics were conducted. These visualizations and descriptions provided a perfect environment for understanding the distribution of the PPR epidemic over space and time. Data visualization and descriptions were used by 34 studies (80.9%), and this was the most reliable method used by all the studies to present the distribution of PPR epidemics. Various analytical approaches used for data visualization and description include GLMNB (11), GLMMs (29) and negative binomial to evaluate the possible risk factors linked to each outbreak's PPR disease case count (1,27). Either linear (13,24,30,31) or logistic regression models were used to explore or test hypotheses related to temporal trends. GeoDa 1.14.0 was used to perform Geographically Weighted Regression (GWR), with climate and geographical variables acting as predictors and log-transformed PPR cumulative incidence serving as the dependent variable (28). Bayesian techniques, such as Bayesian Time-Scaled Phylogenetic Analysis, were used in other investigations (2,3,44) along with the empirical Bayesian kriging (EBK) technique for risk map generation and geostatistical prediction. NAADSM (North American Animal Disease Spread Model (12), autoregressive integrated moving average model (ARIMA) (35), least cost path (LCP) (36), The Naïve Bayes (NB) and Random forest machine learning algorithms (26), ensemble algorithm(37), regression tree models (26) and Mantel correlograms (13) which was employed to examine the relationship between genetic distances and various measures of geographical and network distance. The seasonal population matrix model was used to assess the ability of different vaccination schedules they can be incorporated into the PPR control program (45). Using ArcGIS v10.4, hot spot and cluster analyses were performed to determine the hot and cold spot regions (1). Maximum Entropy Ecological Niche (MaxEnt) modelling was employed to detect suitable areas for PPR virus distribution (46). GIS-based multi-criterion decision analysis was used to identify areas at risk of PPR occurrence and spread (43). To investigate how the virus spreads during memoryless state transitions in Afghanistan, an event-driven model of PPR derived from the susceptible-exposed-infectious-recovered (SEIR) model was employed (38).

3.7. Epidemiological risk factors associated with PPR epidemics

Nine studies found that socioeconomic factors significantly influence PPR risk, despite trade and commerce, environment, ecology, animal demographics, spatial accessibility, and other epidemiological features accounting for a larger proportion. Risk factors linked to PPR outbreaks in Asia and Africa are identified in the review, as shown in Figure 6 and Sup. Table 4. Two studies were not examined, and epidemiological parameters were incorporated across studies, indicating a consistent risk pathway linking them to outbreaks. The study lists all examined covariables in detail in Figure 6 and Sup. Table 4.

Figure 6: Distribution of models, at regional and subregional, containing variables from every category in the conceptual framework

3.7.1. Livestock demographics and livestock–wildlife interactions

According to Sup. Table 2 The primary objective of twenty studies (six in Africa, twelve in Asia, and one worldwide) was to identify hotspots by examining the impact of susceptible livestock populations on PPR risk. Sheep and goat populations were reported as a covariate more frequently than other susceptible species, even though many other species were taken into consideration (e.g. camel, cattle and pigs) (Sup. Table 2). In 3 out of 17 studies, there was a correlation between a small ruminant population size and sheep and goat density, or a higher risk of PPR. (19,32,47). In general, 47.4% (7/19) of research done in Asia and Africa linked this category of wildlife-livestock interaction to PPR risk.

3.7.2. Livestock Trade

Livestock trade-related factors were included in 19 studies, 9 in Africa and 10 in Asia, as in Sup. Table 2. Eight studies (three in Africa and five in Asia) included the distance or adjacency to an international boundary in their models, demonstrating the common goal of examining the impact of international connections on PPR risk using proxy variables that represented the likelihood of an international trade network or cross-border movements. Six investigations found that the incidence of PPR decreased with increasing distance to an international border (11,13,27,36,48,49). Additionally, elements of the dynamics of the market were taken into account, such as the movement of live animals or their products. Finding the markets in China, Ethiopia, Uganda, and Comoros was crucial for determining the outbreaks in those countries (1,11,47,50). Two investigations examined the relationship between PPR epidemics and human demography (25,49).

3.7.3. Accessibility and networks

Using topographical and landscape factors such as water bodies and permanent transport networks, 14 research (five in Africa, seven in Asia, and two worldwide) investigated PPR risk (Sup. Table 2). Studies in African countries show a link between spatial accessibility and PPR risk, while Asia has a different association. The greater risk is found near major transportation routes or dense road networks (11,43). According to one Ethiopian study, one of the primary indicators of PPR transmission was the quantity of successful encounters per unit of time (at pastures or watering spots, as well as through live-animal commerce) (33). Four studies assessed the influence of natural landscape elements on inland waterbodies and rivers, with only one highlighting the buffering effect of adjacent water bodies against PPR (25).

3.7.4. Association between environmental factors and PPR epidemics

The review of 13 studies on PPR outbreak risks, including those in Africa, globally, and Asia, identified 10 environmental and ecological factors as key categories (Sup. Table 2). The most frequently analyzed features were season, temperature and precipitation (1,22,24–26,30,37,49). Landscape was also assessed by five studies (25,31,42,49). Seasonality, landscape, weather, and climate-related covariables are strongly linked to PPR epidemics, with lower altitudes being more associated with PPR risk compared to higher attitudes (25,27,49). Temperature, precipitation, humidity, sun radiation, wind speed, and other variables that affect land cover status all have an impact on PPR epidemics. (25,26,37). Studies in Asia (4/4) and Africa (3/15) found a correlation between PPR risk and ecological features, but the variables investigated varied, indicating different analysis goals.

3.7.5. Economic and social advancement

Only 9 research (Sup. Table 2) (27)used socioeconomic data to evaluate the risks of PPR spread globally and in the Republic of Kazakhstan, respectively, using socioeconomic and geographic factors such as landscape characteristics. The literacy rate and the availability of veterinary services (such as the number of veterinarians, technicians, and animal health professionals) were the subjects of two studies (47) (25), one conducted in Asia and the other in Africa. Poor animal health and veterinary services assessed in Mandi City, northwest of India, have increased the risk of PPR infection (25). The contribution of the urban population to PPR epidemics was reported by two studies, one in Africa and the other in Asia (25,35).

3.8. PPR transmission dynamics and respective control measures

To illuminate the important PPR transmission dynamics, evaluation of PPR risks was done in almost all studies except two (9,17), which have not explicitly evaluated this covariate. Four studies have explicitly evaluated the transmission dynamics to the control (33,35,39,41). The first one was conducted in Ethiopia and uses a metapopulation model that mimics PPRV spread to evaluate the degree of PPRV transmission in endemic situations. (33). The second one uses a mathematical model to assess the impact of four vaccination strategies implemented at different times in reducing the PPR burden (41). In India, Susceptible-Exposed-Infectious-Removed (SEIR) were used to evaluate PPR transmission dynamics (35). Another study conducted in Tanzania has provided evidence of the PPR transmission pattern (39). However, the probability of PPR transmission is linked to some covariables evaluated in this review; only 13 studies are influenced by livestock contact. Livestock movement as the main contact parameter in PPRV transmission has been evaluated using network analysis to identify PPRV hot spots (13). Those covariables included temporal and spatial aspects, production systems and the use of PPR control strategies such as vaccination and early reporting systems (9,25). Additionally, all six studies assessing the effectiveness of immunization found that regions taking part in PPR vaccination programs had a lower probability of PPR outbreaks (Sup. Table 2). Despite the indisputable significance of PPR transmission dynamics, most studies have used temporal and spatial resolution during epidemiological data collection. The diverse range of these linked covariables has included all epidemiological parameters in this review.

4. Discussion

PPR epidemics have significantly impacted African and Asian economies, requiring spatial and spatiotemporal approaches for disease management. However, uneven load may be due to diverse data sources and analytical approaches. An increasing trend is seen in studies using spatial and temporal analysis for estimating PPR risks in endemic countries (21). This review highlights the improvement in understanding disease risk tracking, control planning, and eventual elimination of PPRV through the assessment of PPR transmission dynamics.

4.1. Modelling approaches

This review analyzes the spatiotemporal distribution of PPR using visualization and descriptive tools. It improves understanding of PPR impact in endemic countries and aids in designing control strategies like vaccines or surveillance buffer zones. As more data becomes available, model development and refinement are crucial for understanding local PPR risks. Predictions need to account for livestock mobility patterns.

4.2. Spatial autocorrelation

Spatial autocorrelation or spatial dependence, is a key component of PPR spatial epidemiology (25). Quantification of spatial autocorrelation in some studies was done by using global spatial autocorrelation indices (21) i.e., Moran's I (25)**,** Mantel test (13), and Getis Ord (27). When evaluating seasonal and temporal changes in disease, it is crucial to analyze spatial-temporal autocorrelation. The identification of outbreaks, clusters, or hotspots might provide clues about the hidden reasons behind the rise in disease incidence and related factors that contribute to endemicity (15). The usefulness of these results is not limited to hotspot detection but it goes further to PPR targeted control measures (proactive or reactive vaccination, culling or depopulating and/or quarantine).

4.3. Temporal trends

Epidemics of PPR like other diseases tend to have seasonal variation due to continuous changes of environmental and ecological factors. In our review, we have identified how these environmental and ecological factors underlying the seasonal transmission of PPR are critical for predicting and understanding the long-term environmental trends and effects on livestock health. PPR spread is influenced by animal contacts, resource sharing, economic activities, and trade. Seasonal variations in precipitation, temperature, and availability of pasture and water can affect livestock mobility and PPR risk projection. Seasonal activities like festivals and dowries during harvest also increase the risk of PPR spread. Control strategies include strategic vaccination and movement restrictions before disease outbreaks. These risk factors vary geographically and demographically.

4.4. Risk factors associated with PPR epidemics

This review examines risk factors related to sheep and goat disease, focusing on demographics and livestock interactions. It highlights the importance of livestock movement, geographic and environmental factors, and the increased density of wildlife or livestock in interface areas. The review also highlights the role of socioeconomic activities in causing interaction between people and animals. Identifying PPR-prone areas is crucial for risk-based surveillance and control measures (43).

4.4.1. Livestock- wildlife Interactions

The impact of livestock–wildlife interactions on the risk of PPR epidemics is linked to the density of susceptible species at livestock wildlife interface areas. In our review, several studies have shown evidence of PPR outbreaks in a protected area to be due to its proximity to a PPR risk area. Few evidence of PPR in wildlife species in Africa is surprising given the increasingly visible epidemics in wildlife in Asia (48). Evidence from our models suggests that the spatiotemporal patterns of PPRV outbreaks in wildlife were similar to those in livestock, suggesting evidence of PPR virus spillover from livestock to wildlife. Global climate changes have resulted in shifts in species distributions and habitat suitability consequently reducing resource availability and increasing wildlife–livestock interactions. In our models, evidence of increased risk of PPR infection due interfered relationship between species, habitat and climate leading to mortalities of wildlife species e.g saiga (*Saiga tartarica tartarica*) in Kazakhstan has been demonstrated (51).

4.4.2. Accessibility and network

Livestock movement is a key risk factor for PPR outbreaks, with most models indicating that geographical infrastructure links are crucial for contact between livestock populations (43). Large water bodies like lakes, rivers, and oceans pose PPR risk due to their accessibility, but poor infrastructure and proximity to water bodies may limit disease spread. Expanding vehicular transportation and limited access to resources may reduce disease contamination. Our review identifies critical sites for PPR transmission in livestock movement, improving local control and surveillance strategies by combining genetic and mobility network data (13).

4.4.3. Social Economic Factors

This review evaluates the impact of socioeconomic factors on the risks of PPR spread, focusing on political, economic, veterinary services, and stakeholders' knowledge. A herd-level event-driven PPR model was created to identify effective management strategies for different herd compositions and circumstances. For example, in Afghanistan, the Lack of scientific data due to due to the political situation has impacted large-scale disease mitigation strategies. A cost-benefit analysis was conducted to assess the economic significance and impact of PPR. Stakeholders' knowledge assessment is crucial for involving livestock keepers in control and eradication programs. The study reveals that social-economic vulnerability, climate change, and risk mitigation strategies, such as livestock mobility and herd diversification, are key drivers of the spread of PPR, influenced by factors such as cultural events, husbandry methods, and economics. Other social practices such as livestock marriage dowries can also promote the spread of PPR to other areas through livestock mobility. The social and political status of PPR endemic countries significantly influences future regional transmission dynamics, necessitating careful consideration of control benefits in cost-benefit analysis for resource mobilization and political will.

4.4.4. Livestock trade

The review examines market dynamics of sheep and goat production linked to PPR risks, examining the likelihood of livestock trade facilitating PPR spread in specific areas. It examines infrastructure like road and railway networks and slaughter facilities. For instance, in Bangladesh, the livestock movement within herds and the central market of the local small and large markets has been connected to the PPR outbreak (28). Another model which evaluates urbanization and habitat characteristics has shown naked evidence of PPR risk to the livestock trade (29). The review highlights regional variations in livestock trade infrastructure, highlighting the need for different control strategies in local contexts. It emphasizes the importance of empowering sub-Saharan countries with livestock trade infrastructure for PPR surveillance and control to meet the 2030 PPR eradication target.

4.4.5. Ecology and environment

Studies on landscape and climatic features linked to PPRV environmental circulation, stability, and survival have been assessed in this review. Results have shown geographical variation in risk magnitude. For example, an area with good precipitation will have good pasture and water supply (42). Shrinkage of Grazing land due to factors like the expansion of conserved areas, agricultural activities and climate change has been linked to PPR risk. In this review, we have been able to identify prediction models which can be used in designing control strategies according to the environment and ecology of the respective area. For example, in China, seasonality pattern identification is critical for vaccination schedules because during summer high temperatures lower animal immunity (36). The ecological niche model discussed in this study has demonstrated how ecological and environmental characteristics are related to PPR outbreaks. The annual maximum temperature was inversely correlated with PPR outbreaks because PPRV is more susceptible to hot temperatures. Other elements, such as seasonal variations in precipitation (warm vs. dry season), exhibited a substantial positive connection with PPR outbreaks, whereas wind speed had a negative association (37). Prediction models allow us to identify the right time for control measures deployment, it becomes ineffective if done outside the time range hence 2030 PPR eradication target has been identified using prediction models (37).

4.4.6. PPR transmission Dynamics

The dynamics of PPR transmission depend on the rate of transmission from PPRV-infected animals to susceptible hosts. In disease models, this rate of transmission is captured in one parameter called the probability of transmission. In our review, several studies have captured spatial transmission dynamic modelling approaches to investigate PPR transmission dynamics and control. These models have been useful in generating scenario analyses of the potential course and severity of PPR epidemics by characterizing and forecasting the spatiotemporal transmission patterns of PPR epidemics, or assessing the effectiveness of interventions and the feasibility of achieving elimination targets (24). In addition to attempting to capture pertinent mechanisms of PPR transmission, such as the possible influence of environmental factors, our review has been able to include important epidemiological characteristics of PPR infection (48). A specific kind of spatial dynamic model known as a metapopulation model divides the population into a number of interacting population groupings based on demographic or spatial data (33). For instance, in Ethiopia, PPRV incursions from lowlands into highlands occur as a result of unequal pasture, water, and animal market distribution, necessitating immunization that targets interfaces between various population sites. Our understanding of PPR transmission dynamics has the potential to achieve a high level of communication speed between the response team in the outbreak event. The outbreak will prompt coordinated events from the point of origin and contributors, immediate epidemiologic characterization on the ground, evaluation to establish spread pathways, and specimen collection to molecular characterization of the virus, all while executing spatial prediction models, using the understanding of PPR transmission dynamics (33).

4.5. Strength

This scoping review provides detailed information on risk-based spatiotemporal techniques for PPR spread in endemic situations. It highlights a promising trend in using spatial epidemiology tools to understand PPR's transmission mechanism. The review identifies areas for future research and highlights methodological limitations in existing studies. It also provides a fair depiction of PPR risk mapping initiatives using a thorough search method in compliance with PRISMA Scoping criteria.

4.6. Limitations.

The study acknowledges the challenge of modelling PPR risks in endemic situations due to the lack of real data and the complexity of approaches. Some models are hypothetical, focusing on mathematical tools for new ideas. The study acknowledges the potential overlooking of relevant publications and studies published in other languages due to the inclusion of only English-published studies.

4.7. Conclusion

Spatial and Spatiotemporal approaches have played a critical role in shifting and improving our understanding of the available disease management options for PPR. However, the uneven burden of PPR may be attributed to the diverse data sources, covariates, and analytical approaches employed. Future development of prediction models to assess potential eradication efforts at national and regional levels should also take Africa into consideration, as many studies have been conducted in Asia as opposed to Africa.

Ethics

Not relevant

Authorization for publishing

Inapplicable

Materials and data accessibility

The corresponding author can provide the datasets used and/or analysed in this study upon reasonable request.

Conflict of interest

There are no conflicting interests, according to the authors.

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Author Contributions

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Data collection: JJM, JNH

Data analysis and interpretation: GM, AC, JJM, JNH

The manuscript was drafted by JJM

The manuscript has been critically revised for significant intellectual content by JNH, GM, AC, SK, DM, EM, EO, GO, and GPO.

Analysis of statistics: JJM

SK, GM, and AC provide administrative, technical, and material support.

Study oversight: SK, GM, and AC

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Supplementary tables (Sup. Tables)

Sup. Table 1: Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

Sup. Table 2: A classification system that includes a comprehensive list of the epidemiological factors that have been reported in the included studies

Sup. Table 3: Features and synopsis of the studies that are included

Sup. Table 4: Index of research papers mentioning at least one covariate associated with the likelihood of PPR outbreaks, broken down by region and subregion.

Sup. Table 5: An overview of techniques for utilizing PPR epidemic data to study spatial, temporal, or spatiotemporal clustering.