DR. GOVINDARAJ GURRAPPA NAIDU (Orcid ID : 0000-0003-3461-2446)

DR. VINAYAGAMURTHY BALAMURUGAN (Orcid ID : 0000-0001-7821-7427)

DR. PARIMAL ROY (Orcid ID : 0000-0001-9028-8463)

Article type : Original Article

Evaluation of effectiveness of Mass Vaccination Campaign against *Peste des petits ruminants* in Chhattisgarh state, India

Running Head: Effectiveness of Mass Vaccination Campaign against PPR

G.Govindaraj[1]*, Goutam Roy[2], B.S.Mohanty[1], V.Balamurugan[1], A.K.Pandey[1], Varsha Sharma[3]Aparna Patel[3], Mausam Mehra[2], S.K.Pandey[2]and Parimal Roy[1]

[1]ICAR-National Institute of Veterinary Epidemiology and Disease Informatics, Post Box No 6450, Yelahanka, Bangalore- 560064, India

[2]Department of Animal Husbandry, Government of Chhattisgarh, Raipur-492001, India.

[3]Animal Disease Diagnostic Laboratory, Department of Animal Husbandry, Government of Chhattisgarh, Raipur - 492001, India

* Corresponding author:govindaraj.naidu@icar.gov.in;mggraj74@gmail.com

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/tbed.13163

Summary

The study evaluated the effectiveness of 'Mass Vaccination Campaign (MVC)' implemented against the contagious transboundary OIE notified *Peste des petits ruminants* (PPR) in sheep and goats on the lines of 'pulse polio campaign' for humans in Chhattisgarh state, India. The effectiveness was evaluated on the axes of adequacy, financial viability under with and without MVC through differencing under various scenarios and options and programme impact from farmer's perspective. The adequacy evaluation revealed that the reported outbreaks, diagnosed and death cases declined under PPR-MVC inconsonance with increased vaccination coverage. Further, the seroconversion increased during post PPR-MVC implies elevated immunity levels in the sheep and goat's population. The estimated mean mortality loss was USD 45.2 and USD 16.5 per animal in goats and sheep, respectively, whereas, the treatment and opportunity cost of labor was USD 1.9 and USD 2.5 per animal, respectively. Under the low PPR incidence scenario, Benefit: Cost Ratio (BCR), Net Present Value (NPV) and Internal Rate of Return (IRR) was 4.9:1, 48.9 million USD and 146.6%, whereas it was 12.4:1,142.7 million USD and 430.4% and 13.5:1,156.7 million USD and 430.4% under medium and high incidence scenarios. Further, the option of vaccinating 100% risk population during first year followed by 30% during subsequent years to cover naïve population will maximize benefits than 100% coverage every year, nevertheless, benefits outweighs cost manifolds in both of these options. The farmers had a positive opinion on the overall services provided under PPR-MVC and the results provide the empirical evidence on effectiveness of 'mass vaccination' for its replication in other states of India or countries with similar socio-economic and rearing environments.

Keywords: *Peste des petits ruminants* (PPR), Mass Vaccination Campaign (MVC), sheep and goats, Effectiveness, Chhattisgarh state, India

Introduction

PPR is an acute and highly contagious viral disease in small ruminants commonly referred as 'goat plague'. The major clinical symptoms of the disease include pyrexia, sore mouth (stomatitis), discharge through ocular and nasal orifices, enteritis diarrhea and bronchopneumonia. The disease causes severe mortality and morbidity in sheep and goats and devastates the livestock inventory of farmers. In developing countries, small ruminants are reared by poor, landless and marginal farmers to supplement agricultural and wage income. Sheep and goat rearing is an important means to achieve equity in the society, hence protecting from production limiting diseases like *Peste des petits ruminants* (PPR) is imperative. PPR was first reported in 1942 in Côte d'Ivoire (Ivory Coast), West Africa, since then the disease has spread to different regions in sub-Saharan Africa, Arabian Peninsula, Middle East and Asia (Balamurugan et al., 2014). The global loss due to PPR has been estimated at USD 1.5 to 2 billion each year (http://www.fao.org/3/a-i4460e.pdf). Due to its huge economic significance to smallholders in developing countries, a global strategy has been planned to control and eradicate PPR by 2030, through vaccine administration.

In India, among the various diseases that limit optimum productivity in sheep and goats, PPR ranks first. The disease was first reported in 1987 from Arasur village, Tamil Nadu state and later spread to other states and the country became endemic for the disease (Singh et al., 2009). In India, annual loss reported in the literature were INR 88,951 million (Singh et al., 2014); INR 16,116 million (Govindaraj et al., 2016) and INR 45,710 to 46,830 million (USD 653-669 million) (Bardhan et al., 2017). Considering the importance of the disease, a live attenuated PPR vaccine that provides immunity for 3 to 6 years was developed by ICAR-Indian Veterinary Research Institute (Sreenivasa et al., 2000). In the initial years of vaccine development, to reduce the disease burden, focused vaccination in outbreak places was adopted since 2002 in few states (Singh et al., 2009), later in programme mode in some states since 2010-11 (Balamurugan et al., 2016), even before the global framework to control PPR was developed. All the Department of Animal Husbandry, Dairying and Fisheries (DADF), Government of India, sponsored PPR-Control Programme (PPR-CP) implemented states followed 100% vaccination of risk population in the first year followed by 30% vaccination at six monthly intervals in the subsequent years to cover the naïve population (Balamurugan et al., 2016), whereas, the state of Chhattisgarh adopted annual 'Mass Vaccination Campaign (MVC)' strategy.

Chhattisgarh accounts for 3.23 million sheep and goats (BAHS, 2014). PPR is endemic and the single largest cause of mortality in small ruminants in Chhattisgarh. Hence, to control the disease the state implemented annual PPR-MVC on the lines of 'Pulse Polio Campaign' for humans through funding from *Rashtriya Krishi Vikas Yojana* (RKVY)/Government of India during 2010-11. The core objectives of PPR-MVC were to achieve 100% vaccination coverage; bringing the outbreaks and epizootics to zero level and to make the state PPR free zone in three years. The annual PPR-MVC involved pre-vaccination, vaccination and post-vaccination phases. In the pre-vaccination phase, establishment of *ad hoc* institutional mechanism like control rooms at state/district level, training and technical workshops for all staff concerned; preparation and distribution of training and extension materials; procurement of required number of vaccines and other items were undertaken. Ten days preceding the mass vaccination, and during the vaccination campaign awareness on PPR vaccination were created through mass media (local dailies and Television advertisement through Jingles). Further, the Hon'ble Minister for Agriculture, Government of Chhattisgarh, communicated letters to all the 9200 Sarpanchs (democratically elected member of a panchayat, the lowest tier in political set-up), agricultural production commissioners, district administrators and Chief Executive Officers of *Zilla panchayats* on the importance of the vaccination campaign and seeking their cooperation and administrative assistance to ensure maximum farmer's participation. In the vaccination phase, annual MVC was implemented in a designated period of 7-12 days in a year; vaccination details (number of animal vaccinated, date of vaccination etc. were documented); daily monitoring and compilation on the progress of the vaccination at village level and vaccination at state borders, goat markets and migratory flocks were carried out. The post-vaccination phase involved collection of 0.1% serum samples for seroconversion analysis.

Even though, MVC was planned for three years (2010-2013), it continued for seven years which warrants assessment of effectiveness of the campaign. The socio-economic impact of PPR in general and vaccination effectiveness in particular is lacking in the endemic countries of this disease including India. The macro-level effectiveness assessment provides evidences and necessary direction for up-scaling in similar socio-economic and rearing environments to reduce PPR disease burden. Hence, the present study attempts to evaluate three axes of PPR-MVC, viz. adequacy (vaccination coverage, number of outbreaks, diagnosed and death cases, and vaccination sero-conversion), financial viability (programme under different scenarios and options) and the programme impact from farmers' perspective.

Materials and methods

Study area

Chhattisgarh state was carved out of Madhya Pradesh state during the year 2000 and is one of the youngest states of Indian Union. It is the tenth-largest state with an area of 134,194 km^2 comprising 27 districts. The state is bordered by Madhya Pradesh state in the northwest, Maharashtra state in the south west, Telangana state in the south, Odisha state in the southeast, Jharkhand state in the north east an Uttar Pradesh state in the North. As per 19th livestock census 2012, the total sheep and goat population in Chhattisgarh is 3,393,530 of which goats constitute 95%.The Chhattisgarh state and the districts where the primary survey was undertaken are presented in Fig.1.

Data sources and Sampling procedure

The times series data collected from various sources and cross-sectional primary survey data collected during 2015-16 in Chhattisgarh were used for assessing the effectiveness of the PPR-MVC. Multistage random sampling technique was followed to collect primary data from sheep and goat rearing farms. In the first stage, Chhattisgarh state was purposefully selected as the state has implemented PPR-MVC. In the second stage, 18 districts in Chhattisgarh state (as per latest available 19th livestock census data,2012) were grouped into four groups based on goat population density using quartiles and one district was selected randomly in each of the quartile groups. Accordingly, Raipur, Mahasamund, Bilaspur and Bastar districts were selected in low, medium, high and very high density groups. In the third stage, in each of the selected district four blocks and in each block, one veterinary dispensary (Outline Dispensary (OLD)) was selected randomly. In the fourth stage, the jurisdictional villages in each of the selected veterinary dispensary (OLD) were listed and five to ten villages were randomly selected. In the fifth stage, the numbers of farms to be surveyed in each of the selected village were based on the proportion of sheep and goat rearing farms among the selected villages. In the last stage, sheep and goat rearing farms were selected randomly in each of the selected villages. For the counterfactual control state (Madhya Pradesh), similar sampling procedure was adopted, except the districts were selected based on PPR risk levels (high, medium and low risk districts).

Sample size

The estimated sample size for the primary survey in Chhattisgarh state was 330 sheep and goat rearing farms as per Cochran, 1963.

$$SS = \frac{Z^2(P)(1-P)}{e^2}$$

where, SS is the required sample size ,

Z is the Z-value (at 95% confidence interval 1.96),

P is the proportion of sheep and goats rearing farm households in Chhattisgarh state as per 19^{th} Livestock Census, 2012 (0.119) and

e is the acceptable sampling error (0.35)

The samples were distributed among the four districts in proportion to population density and accordingly 92, 96, 72 and 70 farms were surveyed in Bilaspur, Mahasamund, Raipur and Bastar districts, respectively (Fig.1). The estimated sample size for the counterfactual control state (Madhya Pradesh) was 410, which were distributed among the three risk districts in proportion to population density.

Schedule and identification of PPR affected farms

The schedule comprised socio-economic profile of farmers, sheep and goat inventory, clinical signs of PPR observed by farmer, incidence of the disease, productivity parameters before and after the disease incidence, treatment cost, perceived market prices of animals of various age groups, opportunity cost of labor etc. The photographs of various clinical signs of PPR were provided to the farmers for identifying the disease infection in the farm. Further, the serum samples were also collected from the farms where PPR was observed by the farmer (based on clinical signs) but not vaccinated. The samples were tested for PPR virus antibodies in the laboratory using PPR c-ELISA (Singh et al., 2004) for confirmation.

Mortality loss, weight loss, treatment cost and opportunity cost of labor

The sheep and goat inventory, clinically diagnosed PPR cases and deaths were considered to estimate the primary metrics of mortality and morbidity levels. The mortality loss was estimated based on the market value of the sheep and goats before the disease and value recovered after death (Govindaraj et al., 2017a). The weight loss was assessed based on average weight reduction (Kg) in the PPR infected and recovered animals multiplied by live weight price (Kg). The treatment cost includes veterinarian fees, drugs, medicines and miscellaneous cost incurred in PPR affected farms were computed and converted to per animal. Similarly, the opportunity cost of labor for nursing the animals was computed based on the number animals reared and number of hours spent by the family members to treat and nurse the affected animals. The market prices of animals of various age groups and the labor wage rate prevailed in the villages during February-March, 2016 was considered for estimating the various losses.

Estimation of cash flows of PPR-MVC

The cash-flows were estimated from the initial year of PPR-MVC implementation (2010) till possible end year (2020) to assess the Benefit: Cost of the programme. The cost stream comprise vaccination and vaccine cost incurred for every year for PPR-MVC. The vaccination cost per year was calculated as below.

$$Vc = \sum_{1}^{n} SN + Pv + Vst + Cst + Pe + VdP + PVsl + Ss$$

Where,

Vc	= Vaccination cost/year (USD)
SN	= Cost incurred for accessories (syringe, needles etc.)/year (USD)
Pv	= Payment to '*hired vaccinators**'/year (USD)
Vst	= Vaccination storage and Transportation cost/year (USD)
Cst	= Cost incurred on sensitization and technical workshops/year (USD)
Pe	= Expenditure on preparation of extension material/year (USD)
Vdp	= Expenditure on vaccination programme dissemination and publication/year (USD)
PVsl	= Expenditure for post-vaccination sero-monitoring & for strengthening the district disease investigation labs/year (USD)
Ss	= Staff salary during the vaccination period/year (USD)
N	= Number of vaccination cost components

**Hired vaccinators* are educated people with basic knowledge on animal rearing and health management and trained on PPR vaccination. They worked under the overall supervision of Veterinary Doctors for a remuneration.

Further, the vaccination cost per dose was calculated by dividing the vaccination cost incurred per year with number of doses vaccinated per year. The vaccine cost for the period 2010-11 to 2016-17 was calculated based on actual doses vaccinated per year multiplied by the price of vaccine per dose, whereas for the period 2017-2020, it was based on the expected vaccine requirement.

The decline in outbreaks, diagnosed and death cases is the benefits realized through PPR-MVC intervention and hence programme was evaluated under *with* and *without* intervention through differencing approach (Gittinger, 1985). For *without* scenario, the disease status in Madhya Pradesh state was considered as counterfactual control as the state has not implemented the 'mass vaccination' with maximum coverage of population till 2015-16 except limited vaccination in the event of few outbreaks. Moreover, Chhattisgarh state was carved out of Madhya Pradesh and a contiguous state with similar socio-economic and livestock rearing pattern. The literacy rate in Chhattisgarh and Madhya Pradesh was 70% (Government of India, 2011) with per capita income of USD 1114 (INR 78,000) and USD 803 (INR 56182) at 2014-15 prices, respectively. In both the states, among small ruminant population, >95 per cent constitute goat population (BAHS, 2014)

PPR incidence levels under *with* and *without* vaccination intervention during before and after MVC is crucial for financial evaluation. The disease incidence in Chhattisgarh before PPR-MVC scenario was not available, hence, incidence level (8%) reported in literature during 2008-09 (Awase et al., 2013) for Madhya Pradesh state was considered. For post PPR-MVC intervention, the incidence level (0.8%) estimated through the primary survey undertaken by the authors during 2015-16 (after six years of PPR-MVC implementation) was considered. Based on these incidences, the stream of incidences in different years between 2009-10 and 2015-16 under *with* vaccination scenario was derived by interpolation through linear method. For the years 2016 to 2020, it was assumed that the incidence level will be zero, as the PPR incidence in Chhattisgarh already reached as low as 0.8% during 2015-16. Under *without* vaccination intervention, in the counterfactual Madhya Pradesh state, the literature reported 8% PPR incidence during 2008-09 and survey estimated 19.5% during 2015-16. Based on these incidences, under *without* vaccination intervention scenario, the stream of incidences in different years between 2009-10 and 2015-16 was derived by interpolation through linear method. Further, the sensitivity analysis under three scenarios {(a) Scenario-1 (low incidence) refers to 8% disease incidence level before the PPR-MVC implementation remains same throughout the period; (b)Scenario-2 (medium incidence) refers to 8% disease incidence level before PPR-MVC increases and reaches 20% by 2020 and (c) Scenario-3(high incidence) refers to the 8% disease incidence level before PPR-MVC increases and reaches 25% by 2020} in *without* vaccination set up were also assessed to understand financial viability of PPR-MVC.

The difference in disease incidences (disease avoidance levels) under various scenarios, unit disease cost and projected population, the stream of avoided costs/benefits due to PPR-MVC implementation was calculated using the formulae provided below.

$$L = \sum_{l=1}^{n} [\ ID * \Pr * DC_l]$$

Where, L= Loss projected due to PPR in a year (USD); ID= difference in disease incidence in that year (%); Pr= Population at risk (sheep and goat population in that year); DC_l= Disease cost of l^{th} component of loss (USD); n= Represents different components of loss (mortality, body weight reduction, treatment cost and opportunity cost of labor)

The benefits derived were adjusted for vaccine effectives and animals vaccinated as per Govindaraj (2017b).

$$Bts = \sum_{1}^{n} [\ L * V * P]$$

Where, Bts = Benefits of vaccination per annum (USD); L = Loss projected in different years (USD); V= Vaccine effectiveness (%); P= Proportion of animals vaccinated (%); n = Represents different sheep and goats species. Since the PPR vaccine provides life-long immunity (3-6 years), 80% vaccine effectiveness was assumed for benefits assessment.

Similarly, the cost per annum were calculated based on

$$Ct = [\ (V + VN) * P]$$

Where, Ct= Total cost of vaccination per annum (USD); V= Vaccine cost/dose (USD); VNc= Vaccination cost/dose (USD); P= population covered (numbers).

In Chhattisgarh, the PPR-MVC was implemented since 2010-11 and hence, benefits in terms of reduced PPR incidence were assumed to start from 2011-12 onwards till possible year (2020) of withdrawal of the PPR-MVC programme. The livestock census data was available for quinquennial periods (2003, 2007 and 2012) and hence for projecting the sheep and goats population during PPR-MVC implementation period, the compound annual growth of sheep and goats during 2003-2012 was considered. The base population for projecting the sheep and goat population between 2008 and 2012 was 2007 livestock census population, and for 2013 to 2020, the 2012 livestock census population.

The financial benefits of the PPR-MVC was evaluated based on Benefit-Cost Ratio (BCR), Net Present Value (NPV) and Internal Rate of Return (IRR) (Rushton, 2009, Jones et al., 2016 Tambi et al., 1999; Blakeway 1995; Rich et al., 2014). The avoided mortality loss, body weight reduction, treatment cost and opportunity cost of labor was considered as benefits and investment made on vaccine and vaccination was considered as cost.

The axes of programme impact in farmers' perspective on various aspects of the PPR-MVC implementation were measured on Likert scale {Strongly Disagree (SD), Disagree (D), Neutral (N), Agree (A) and Strongly Agree (SA)} with positive and negative statements.

Statistical analysis

Descriptive statistics and *Chi*-square test to assess the significant differences in clinically diagnosed and death cases and Case Fatality Rate (CFR) between breeds and age groups were carried out using SPSS version 22.0.

Results

Vaccination coverage, seroconversion and outbreaks

The reported PPR vaccination coverage had increased from 61% (2010-11) to 91.6% (2015-16) after PPR-MVC implementation. Similarly, the vaccination protection against PPR increased from 40% (512 samples positive out of 1280) before PPR-MVC implementation to 80% (2619 samples positive out of 3093). The data on outbreaks, diagnosed and death cases during pre-PPR-MVC implementation in Chhattisgarh was not available, nevertheless, after PPR-MVC, in consonance with increased vaccination coverage, only two outbreaks with 647 diagnosed and 272 death cases were reported during 2010-12. Further, no outbreaks were reported in Chhattisgarh state since 2012-13 onwards, but, the primary survey (n=330) backed by laboratory testing of serum samples revealed sporadic incidence (0.8%) during 2015-16. Further, the clinically diagnosed and death cases observed in sheep was 3% each, whereas it was 0.6% and 0.3% in goats, respectively. The disease incidence was observed more in young animals (< 6 months old) than older animals (> 6 months old) in both the species. The *Chi*-square results revealed significant difference in clinically diagnosed and death cases and Case Fatality Rate between sheep and goats species (Table 1).

Estimated loss per animal

The estimated mean mortality loss per animal was USD 45.2 and USD 16.5 in goats and sheep, respectively. The body weight loss per animal in goats was USD 23.5 and treatment and opportunity cost of labor was USD 1.9 and USD 2.5, respectively. In sheep, mortality loss was highest (79%) followed by opportunity cost of labor (12%) and treatment cost (9%) whereas in goat major loss was mortality loss (62%) followed by weight loss (32%), opportunity cost of labor (3%) and treatment cost (2%). The details of estimated various tangible losses associated with PPR are presented in Table 2.

Financial feasibility of PPR-MVC

Under low disease incidence level, the benefits increased from USD 1.77 million during 2011 to USD 9.28 million in 2020 whereas the benefits increased two and three times under medium and high PPR disease incidence scenarios (Table 3). The estimated vaccine cost was USD 3/100 dose (INR 1.8/dose or INR 180/100 dose) during 2015-16 whereas vaccination cost was USD 30.3/100 dose (INR 18.2/dose or INR 1820/100 dose). The overall cost of vaccination against PPR after PPR-MVC implementation in the state increased from USD 0.97 million during 2010 to USD 1.35 million during 2020. The financial feasibility results under low PPR disease incidence scenario revealed that, BCR, NPV and IRR were 4.9:1, 48.9 million USD and 146.6%, respectively. Under medium and high disease incidence scenarios it was 12.4:1,142.7 million USD and 430.4% and 13.5:1,156.7 million USD and 430.4%, respectively (Table 3). Further, when the scenarios were compared under two methods of vaccination, the alternative option (vaccinating 100% risk population followed by 30% vaccination of naïve population every six months in a five year cycle and if needed to repeat one more cycle) provided maximum benefits than the 100% coverage every year as adopted by the state (Table 4).

Vaccination adoption and farmers perception on PPR-MVC

Among sample farmers, 97% adopted PPR vaccination covering 80% of their sheep and goats during 2015-16 (Table 5). The farmer's perception on PPR-MVC revealed majority of them concurred with the positive statements and disagreed for the negative statements implying the positive opinion on the annual vaccination programme in Chhattisgarh (Table 6).

Discussion

The effectiveness of mass vaccination campaign in the field of animal health is limited, though it aids in decision making. In this study three axes of PPR-MVC namely adequacy indicators (Habicht et al., 1999), financial viability and programme impact in farmer's perspective were studied to assess the overall effectiveness of the programme implemented in Chhattisgarh, India.

The evaluation on adequacy axes revealed that the vaccination coverage through annual MVC increased every year and reached 80% within seven years and no outbreaks were recorded by the Animal Husbandry Department, Government of Chhattisgarh since 2012-13 indicates the effective PPR-MVC implementation. The livestock disease reporting is a concern in many countries due to various administrative and other reasons, hence to corroborate the disease status after PPR-MVC, the primary survey undertaken during 2015-16 in Chhattisgarh revealed only 0.8% incidence (sporadic occurrence). This incidence was very low compared to 19.5% incidence level during 2015-16 in non-vaccination implemented Madhya Pradesh state and also Indian scenario (8 to 12% incidence) (Govindaraj et al., 2016, Bardhan et al., 2017), indicating the rollout of the MVC programme in Chhattisgarh has been successful. Further, only 11 farms in one district (out of 330 sheep and goat rearing farms from four districts surveyed) observed PPR indicating sporadic incidence of the disease.

In general, the post-vaccination seroconversion levels provide evidence on the effect of vaccination as well as effectiveness of veterinary service in the area (Gitonga, 2015). The post-vaccination seroconversion levels on testing 0.1% of samples was higher (~ 70%) than OIE recommended levels (http://www.fao.org/3/a-i4460e.pdf) whereas, cross sectional stratified random sample serosurvey revealed 55% protection (Balamurugan et al., 2018). Despite higher protection than pre PPR-MVC level (40%), the threat persists from ingress of disease from other bordering states due to unabated movement of animals across the states for grazing, transit and trade. Hence, vaccination on the migratory sheep and goats population at animal movement corridors/ check posts/ animal markets close to borders of other states and emphasising vaccination of animals 2-3 weeks prior to entry into the state needed to be implemented strictly to maintain the attained protective immunity levels in the population. Further, Balamurugan et al., (2018), had advocated vaccination till 2019-20 to attain the desired protection levels in the population. Though it is not advisable on scientific grounds and cost perspective to vaccinate 7-10 years, considering various field problems in developing countries, the extended period of vaccination is necessary to maintain the attained protective immunity levels. Further, the maximum investment needed to undertake annual vaccination is less than USD 2 million, but paybacks are manifold.

The study observed variation in loss per animal between sheep and goats due to various factors like differences in disease severity levels, age and sex composition of flocks, price etc. The axes of financial feasibility evaluation of PPR-MVC considering the benefits of disease avoidance indicated maximum benefits (BCR 4.90:1; IRR 146.61). The earlier studies also projected maximum benefits of global eradication of PPR (BCR 33.8 and IRR of 199%) (Jones et al., 2016). Further, studies on the benefits of Pan-African Rinderpest Campaign (PARC) revealed BCRs ranged from 1.06 to 3.84 (Tambi et al., 1999; Blakeway 1995) and vast benefits to South Sudan (BCR of 34), whereas Rich et al., 2014 estimated baseline BCR of 4.02 for rinderpest control. In India, the projected PPR vaccine research and development benefits using economic surplus model and its associated assumptions was NPV of INR 489,150 million BCR of 123%, and IRR 119% (Bardan et al., 2017). Though the financial estimates of present study is not directly comparable due to variation in geographical coverage of vaccination, risk population, variation in up-stream and down-stream parameters, assumptions considered in building the models, time lag and exchange rate variation etc. it provides an indication on the possible impact of the disease and its financial viability, if implemented on a programme mode. The sensitivity analyses for the various disease incidence scenarios indicated high gains even under very low incidence and provides a conservative estimate of disease avoidance benefits. Further, the vaccination benefits under two methods of vaccination indicated that under alternative option (vaccinating 100% risk population followed by 30% vaccination every six months to cover the naïve population for a designated period) that is adopted in some states of India under Department of Animal Husbandry, Dairying and Fisheries (DADF), Government of India sponsored PPR-Control Programme (PPR-CP) provided maximum benefits than the 100% coverage every year as adopted in Chhattisgarh. However, the implementation success of this option depends on the veterinary institutional infrastructure coverage, funds and technical manpower availability for MVC. The identification of naïve population for vaccine administration in the subsequent years of mass vaccination is a difficult proposition as tagging the vaccinated animals were not practiced in MVC. Further, many farmers sought vaccination for all the animals during subsequent year's rather than for naïve population only, implying the difficulties in implementing the alternative option of vaccination under real field situations. Hence, farmers need to be educated on the lifetime immunity of the vaccine and the need of vaccination only once to maximize MVC benefits at least-cost. However, irrespective of the vaccination options, the benefits significantly outweighed the cost which indicate PPR-MVC's financial viability.

The vaccination in animals is an important palliative means to prevent highly infectious diseases (Rathod et al., 2016) however, volunteering by farmers to vaccinate their animals is limited in developing countries like India as majority of farmers are unaware about important livestock diseases and do not realize its socio-economic consequences till outbreak occur in their farms. The axes on programme impact revealed that the vaccination adoption levels and number of animals vaccinated against PPR was high due to the institutional 'big push' and public health commitment to control the disease through exclusive 'pulse polio' mode as adopted in humans. The disease incidence has declined significantly in some Indian states due to mass vaccination (Balamurugan et al., 2016), however, the effectiveness of programme depends on various facets of planning to implementation including support and acceptance of the farmers. The compliance of farmers is particularly relevant in developing countries as livestock is important from poverty relief perspective (Rich and Perry 2011). Majority of the farmers opined that the animal husbandry department besides highlighting the importance of PPR vaccination, communicated time and place of mass vaccination through mass media (Radio, Television and local dailies), provided extension materials and most importantly vaccination were carried out door to door in majority of the villages. Further, the panchayat (democratically elected local representatives) involvement in the process ensured more farmers participation in MVC. At broader level, the study provides evidences on the operational and financial feasibility of PPR-MVC implemented in Chhattisgarh state of India and can be a model for implementation in similar livestock rearing environments. However, the results of the present study need to be visualized with certain limitations like the cost of the disease burden focused mainly on mortality and morbidity, treatment expenditure and opportunity cost of labor whereas other spin-off impacts in the entire value chain and economy-wide dynamic effects through livestock associated sectors were not considered. Further, majority of the small ruminant farmers are marginal and small and their dependence on sheep and goats rearing has immense bearing on social and economic life especially on income generation, livelihood security and relief from poverty. The inclusion of these factors would have compounded the disease control benefits assessed in the study.

Conclusions

The availability of a potent vaccine, establishing an enabling institutional mechanism, association with administrative machinery and grass-root democratic institutions ensured participation of farmers in large numbers in the MVC which resulted in reduced disease incidence levels and benefits outweighed the cost in manifolds. However, the success gained will be eliminated, if, not protected from the unvaccinated migratory, transit and trade movement of sheep and goats from the states that share a contiguous border with Chhattisgarh. Hence, to combat, control and eradicate the disease in the long-run and to protect from re-introduction from bordering states, animals at entry points of migratory corridor and border check posts need to be vaccinated, preferably 2-3 weeks prior to entry to maintain the constant immune population in the state. Further, other states need to implement a vaccination programme diligently in lines of Chhattisgarh's PPR-MVC or in their own terms to prevent the disease spread. The federal government also need to actively plan and co-ordinate the mass vaccination in consultation with various states based on disease risk levels, population density, migratory pattern, vaccine availability to combat the disease effectively. The PPR vaccination programme need to be considered as a public good as it benefits millions of small, marginal and landless farmers and countries need to proactively plan and invest funds in the programme to control and eradicate the disease globally by 2030, as envisaged by FAO and OIE.

Acknowledgements

Authors acknowledge ICAR, ICAR-NIVEDI staff for their constant support. Authors appreciate the efforts of Chhattisgarh State Animal Husbandry Department and their officials, field veterinarians, para-veterinarians for their assistance during data collection and thank the sheep and goats rearing farmers for their active participation in the survey. This work was supported by Indian Council of Agricultural Research (ICAR), Agricultural Extension Division through Extramural project (grant file number A.Extn.26/5/2106-AE-I/13).

Conflict of interests

The authors declare that they have no conflict of interests.

References

Awase, M., Gangwar, L.S., Patil, A.K., Goyal, G., & Omprakash (2013). Assessment of economic losses due to *Peste des Petits Ruminants* (PPR) disease in goats in Indore Division of Madhya Pradesh. *Livestock Research International,1*, 61-63.

BAHS (2014). 19th Livestock Census. Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi, India

Balamurugan, V., Hemadri, D., Gajendragad, M. R., Singh, R. K., & Rahman, H. (2014). Diagnosis and control of peste des petits ruminants: a comprehensive review. *Virus Disease*, *25*, 39–56.

Balamurugan, V., Govindaraj, G., & Rahman, H. (2016). Planning, implementation of Peste des petits ruminants control programme and strategies adopted for disease control in India. *British Journal of Virology*, *3*, 53-62.

Balamurugan, V., Muthuchelvan, D., Govindaraj, G., Goutam Roy., Varsha Sharma, Sowjanyakumari, S., Dheeraj Choudhary., Mohanty, B.S., Suresh, K.P., Rajak, K.K., Hemadri, D., & Parimal Roy. (2018). Serosurvey for assessing PPR vaccination status in rural system of Chhattisgarh state of India. Small Ruminant Research, 164.---. https://doi.org/10.1016/j.smallrumres.2018.05.011

Bardhan, D., Kumar, S., Anandsekaran, G., Chaudhury, J. K., Meraj, M., Singh, R. K., Verma, M. R., Kumar, D., Kumar, P. T. N., Ahmed, S. L., Mishra, V., Mohanty, B.S., Korade, N., & De, U.K. (2017). The economic impact of peste des petits ruminants in India. *Revue scientifique et technique (International Office of Epizootics)*, *36*, 245-263.

Blakeway, S. (1995). Evaluation of the UNICEF Operation Lifeline Sudan, Southern Sector Livestock Programme, Unicef-OLS, Nairobi.

Government of India, (GoI, Census Report) (2011): Registrar general and census commissioner, New Delhi

Cochran, W.G. *Sampling Techniques*, Wiley, New York, 1963.

Govindaraj, G., Balamurugan, V., & Rahman, H. (2016). Estimation of economic loss of PPR in sheep and goats in India: An annual incidence based analysis. *British Journal of Virology*, 3, 77-85.

Govindaraj, G., Ganeshkumar, B., Nethrayini, K. R., Shalini, R., Balamurugan, V., Pattnaik, B., & Rahman, H. (2017a). Farm Community Impacts of Foot-and-Mouth

Disease Outbreaks in Cattle and Buffaloes in Karnataka State, India. *Transboundary and Emerging Diseases*, *64*, 849-860.

Govindaraj, G., Krishnamoorthy, P., Nethrayini, K. R., Shalini, R., & Rahman, H. (2017b). Epidemiological features and financial loss due to clinically diagnosed Haemorrhagic Septicemia in bovines in Karnataka,India. *Preventive Veterinary Medicine*, *144*, 123-133.

Gitonga, P. (2015). Spatial analysis of risk factors and their effects on peste des petits ruminants control strategies in Kajiado and Marsabit pastoral systems of Kenya.

Gittinger, J. P. (1985). *Economic analysis of agricultural projects*. Unnumbered series ; no. UNN 76. Washington, DC: World Bank. (http://documents.worldbank.org/curated/en/584961468765021837/Economic-analysis-of-agricultural-projects)

Habicht, J. P., Victora, C. G., & Vaughan, J. P. (1999). Evaluation designs for adequacy, plausibility and probability of public health programme performance and impact. *International Journal of Epidemiology*, *28*, 10-18.

Jones, B. A., Rich, K. M., Mariner, J. C., Anderson, J., Jeggo, M., Thevasagayam, S., Cai Yi, Peters, A. R., & Roeder, P. (2016). The economic impact of eradicating Peste des Petits Ruminants: A Benefit-Cost Analysis. *PLoS One*, *11*, e0149982.

Rathod, P., Chander, M., & Bangar, Y. (2016). Livestock vaccination in India: an analysis of theory and practice among multiple stakeholders. *Revue Scientifique et Technique (International Office of Epizootics)*, *35*, 729-739.

Rich, K. M., & Perry, B. D. (2011). The economic and poverty impacts of animal diseases in developing countries: new roles, new demands for economic and epidemiology. *Preventive Veterinary Medicine*, *11*,133-147.

Rich, K. M., Roland-Holst, D., & Otte, J. (2014). An assessment of the *ex-post* socio-economic impacts of global rinderpest eradication: Methodological issues and applications to rinderpest control programmes in Chad and India. *Food Policy*, *44*, 248-261.

Rushton, J (2009). The economics of animal health an production, CABI, UK.

Sreenivasa, B.P.,Dhar,P., Singh, R.P. & Bandyopadhyay, S.K. (2000). Evaluation of an indigenously developed homologous live attenuated cellculture vaccine against Peste-des-petits-ruminants infection of small ruminants. Proceedings of XX Annual Conference of Indian Association of Veterinary Microbiologists, Immunologists and Specialists in Infectious Diseases (IAVMI), Pantnagar, Uttaranchal, India, 84

Singh, R. P., Sreenivasa, B. P., Dhar, P., Shah, L. C., & Bandyopadhyay, S. K. (2004). Development of monoclonal antibody based competitive ELISA for detection and titration of antibodies to peste des petits ruminants (PPR) virus. *Veterinary Microbiology*, *98*, 3-15.

Singh, B., Bardhan, D.,Verma,M.R., Shiv Prasad & Sinha,D.K. (2014). Estimation of economic losses due to Peste de Petits Ruminants in India. *Veterinary World*, 7, 194-199.

Singh, R. K., Balamurugan, V., Bhanuprakash, V., Sen, A., Saravanan, P., & Yadav, M. P. (2009). Possible control and eradication of peste des petits ruminants from India: technical aspects. *Veterinary Italia,* 45, 449-462.

Tambi, E. N., Maina, O. W., Mukhebi, A. W., & Randolph, T. F. (1999). Economic impact assessment of rinderpest control in Africa. *Revue Scientifique at Technique de l Office International des Epizooties, 18,* 458-477.

Table 1. Details of animals at risk, diagnosed and death cases and CFR in Chhattisgarh during 2016

Particulars	Animals at risk (Number)	Diagnosed cases (Number)	Death cases (Number)	CFR (%)
Breed				
Sheep	968	29 (3.0)	29 (3.0)	100.0
Goats	7321	41 (0.6)	23 (0.3)	56.1
Total	8289	70 (0.8)	52 (0.6)	74.3
Chi-square value		60.580***	98.63***	17.14***
Age wise (sheep and goats)				
< 6 months	1892	21 (1.1)	21 (1.1)	100.0
6-12 months	1884	16 (0.8)	16 (0.8)	100.0
> 1 year	4513	33 (0.7)	15 (0.3)	45.5
Chi-square value		2.28 (0.32)	14.86***	27.17***

CFR= Case fatality Rate

Table 2. Estimated loss per animal (USD) in Chhattisgarh during 2016

Components of loss	**Sheep**	**Goats**
Mortality	16.5	45.2
	(2.7, 9.7-31.3)	(4.1, 20.9-62.7)
Body weight reduction	-	23.5
		(3.7, 14.9-29.9)
Treatment expenditure	1.9	1.9
	(0.2, 1.3-3.0)	(0.2, 1.3-3.0)
Opportunity cost of labor	2.5	2.5
	(1.2, 0.3-10.5)	(1.2, 0.3-10.5)

The figures in parentheses indicate standard error of mean and range values

Table 3. Financial viability of the PPR-MVC implemented in Chhattisgarh (100% vaccination coverage every year)

Year	PPR incidence under *without* vaccination (%)			PPR Incidence under *with* vaccination (%) (D)	Difference in Incidence (%)			Vaccine coverage (%)	Vaccine effectiveness (%)	Estimated avoided average loss under different scenarios corrected for vaccine effectiveness(USD in millions) (Bts)			Total Vaccination Cost (USD in millions) (Ct)	Financial viability measures		
	Low& (A)	Medium& (B)	High& (C)		Low& (A-D)	Medium& (B-D)	High& (C-D)			Low&	Medium&	High&		Low&	Medium&	High&
2010	8.00	9.64	9.64	6.97	1.03	2.67	2.67	100	80	-	-	-	0.97			
2011	8.00	11.29	11.29	5.94	2.06	5.34	5.34	100	80	1.77	4.60	4.60	1.00			
2012	8.00	12.93	12.93	4.91	3.09	8.01	8.01	100	80	2.69	6.98	6.98	1.01			
2013	8.00	14.57	14.57	3.89	4.11	10.69	10.69	100	80	3.71	9.64	9.64	1.05			
2014	8.00	16.21	16.21	2.86	5.14	13.36	13.36	100	80	4.81	12.49	12.49	1.09			
2015	8.00	17.86	17.86	1.83	6.17	16.03	16.03	100	80	5.98	15.54	15.54	1.13			
2016	8.00	19.50	19.50	0.80	7.20	18.70	18.70	100	80	7.23	18.79	18.79	1.17			
2017	8.00	19.63	20.88	0.00	8.00	19.63	20.88	100	80	8.33	20.44	21.74	1.21			
2018	8.00	19.75	22.25	0.00	8.00	19.75	22.25	100	80	8.64	21.32	24.02	1.26			
2019	8.00	19.88	23.63	0.00	8.00	19.88	23.63	100	80	8.95	22.24	26.44	1.30			
2020	8.00	20.00	25.00	0.00	8.00	20.00	25.00	100	80	9.28	23.20	29.00	1.35			
													BCR	4.90	12.38	13.50
													NPV (in USD millions)	48.86	142.69	156.69
													IRR	146.61	430.41	430.42

Low&, medium& ,and high& represents disease incidence level before the PPR-CP implementation remains same throughout the PPR-CP period; the disease incidence increases from 8% (before PPR-CP) and reaches 20% by 2020 and ; the disease incidence increases from 8% (before PPR-CP and reaches 25% by 2020.

.

Table 4. Financial viability of alternative option of mass vaccination (100% vaccination coverage first year followed by 30% coverage three years and need based coverage in the fifth year)

Year	PPR incidence under *without* vaccination (%)			PPR Incidence under *with* vaccination (%) (D)	Difference in Incidence (%)			Vaccine coverage (%)	Vaccine effectiveness (%)	Estimated average loss under different scenarios corrected for vaccine effectiveness(USD in millions)(Bts)			Total Vaccination Cost (USD in millions) (Ct)	Financial viability measures		
	Low[&] (A)	Medium[&] (B)	High[&] (C)		Low[&] (A-D)	Medium[&] (B-D)	High[&] (C-D)			Low[&]	Medium[&]	High[&]		Low[&]	Medium[&]	High[&]
2010	8.00	9.64	9.64	6.97	1.03	2.67	2.67	100	80	0.00	0.00	0.00	0.97			
2011	8.00	11.29	11.29	5.94	2.06	5.34	5.34	30	80	1.77	4.60	4.60	0.30			
2012	8.00	12.93	12.93	4.91	3.09	8.01	8.01	30	80	2.69	6.98	6.98	0.30			
2013	8.00	14.57	14.57	3.89	4.11	10.69	10.69	30	80	3.71	9.64	9.64	0.32			
2014	8.00	16.21	16.21	2.86	5.14	13.36	13.36	10*	80	4.81	12.49	12.49	0.11			
2015	8.00	17.86	17.86	1.83	6.17	16.03	16.03	100	80	5.98	15.54	15.54	1.13			
2016	8.00	19.50	19.50	0.80	7.20	18.70	18.70	30	80	7.23	18.79	18.79	0.35			
2017	8.00	19.63	20.88	0.00	8.00	19.63	20.88	30	80	8.33	20.44	21.74	0.36			
2018	8.00	19.75	22.25	0.00	8.00	19.75	22.25	30	80	8.64	21.32	24.02	0.38			
2019	8.00	19.88	23.63	0.00	8.00	19.88	23.63	10*	80	8.95	22.24	26.44	0.13			
2020	8.00	20.00	25.00	0.00	8.00	20.00	25.00	10*	80	9.28	23.20	29.00	0.13			
													BCR	13.7	34.65	37.78
													NPV(in USD millions)	56.91	150.75	164.75
													IRR	201.14	495.44	495.45

* 10% coverage of vaccination in border and vulnerable areas during fifth year of the cycle; Low[&], medium[&] ,and high[&] represents disease incidence level before the PPR-CP implementation remains same throughout the PPR-CP period; the disease incidence increases from 8% (before PPR-CP) and reaches 20% by 2020 and ; the disease incidence increases from 8% (before PPR-CP and reaches 25% by 2020.

Table 5. PPR vaccination levels among the sample farmers in the study districts in Chhattisgarh during 2016

Particulars	Bastar	Bilaspur	Mahasamund	Raipur	Pooled
Total farms surveyed(number)	70	92	96	72	330
Total farms vaccinated (number)	59	92	96	72	319
	(84.0)	(100.0)	(100.0)	(100.0)	(96.7)
Total sheep and goats in the farms(number)	2068	1713	2467	2112	8360
Sheep and goats vaccinated (number)	1520 (73.5)	1403 (81.9)	1983 (80.4)	1790 (84.8)	6696 (80.1)
Sheep and goats not-vaccinated (number)	548 (26.5)	310 (18.1)	484 (19.6)	322 (15.3)	1664 (19.9)

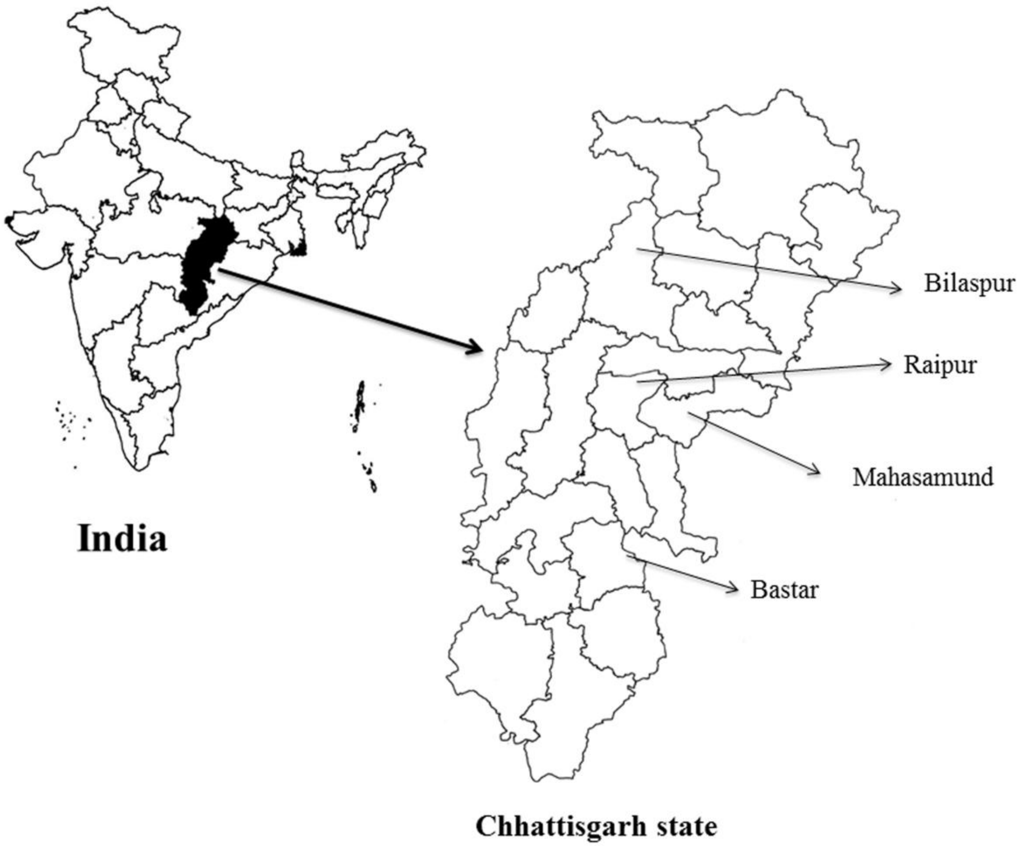
Note: Figures in the parenthesis indicates percentage to total

Table 6. Farmer's perception on PPR-MVC activities in Chhattisgarh during 2016

(n=330 farmers)

Statements	**No. of farmers**				
	SD	**D**	**N**	**A**	**SA**
Sufficient information is provided well in advance about PPR mass vaccination	7 (2.1)	21 (6.4)	40 (12.1)	142 (43.0)	120 (36.4)
Time of Vaccination is appropriate	7 (2.1)	1 (0.3)	0 (0.0)	137 (41.5)	185 (56.1)
Place of Vaccination is suitable	1 (0.3)	2 (0.6)	33 (10.0)	112 (33.9)	182 (55.2)
Satisfied by the PPR vaccination services	1 (0.3)	105 (31.8)	24 (7.3)	78 (23.6)	122 (37.0)
Extension materials on PPR are provided	0 (0.0)	10 (3.0)	48 (14.6)	159 (48.2)	113 (34.2)
PPR like disease is observed in the village even after PPR vaccination	121 (36.7)	152 (46.1)	12 (3.6)	29 (8.8)	16 (4.9)
Most people in your village vaccinate during the 'mass vaccination' campaign regularly	8 (2.4)	6 (1.2)	42 (12.7)	109 (33.0)	165 (50.0)
Is this mass vaccination programme is different from other vaccination programme in terms of more people participation	11 (3.3)	52 (15.8)	53 (16.1)	81 (24.6)	133 (40.3)
There was adverse reaction in animals after PPR vaccination	105 (31.8)	197 (59.7)	22 (6.7)	4 (1.2)	2 (0.6)

SD- Strongly agree, D-Disagree, N -Neutral, A -Agree, SA - Strongly agree


Bilaspur
Raipur
Mahasamund
Bastar
India
Chhattisgarh state