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Basic reproduction number (R_0), an epidemiological tool for prioritizing livestock diseases—An example of Karnataka

P KRISHNAMOORTHY*, K P SURESH, R DHEERAJ and PARIMAL ROY

ICAR-National Institute of Veterinary Epidemiology and Disease Informatics, Bengaluru, Karnataka 560 064 India

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ABSTRACT

Livestock diseases become burden to the dairy farmers and state animal husbandry departments, and causes huge economic loss. Basic reproduction number [R_0], indicates the number of secondary cases in susceptible population from one diseased animal. In the present study, R_0 was calculated by using 5 statistical methods for 13 livestock diseases, which was used to prioritize livestock diseases and calculated herd immunity threshold, vaccination coverage required. Time series data on livestock disease outbreaks, month, year, clinically diagnosed cases, death cases were collected from Department of Animal Husbandary and Veterinary Services. Govt. of Karnataka during the period 2000–18. The mean R_0 values were >1 for bacterial (4), viral (5) and parasitic (4) diseases. The livestock diseases were prioritized for high transmission potential as haemorrhagic septicaemia [HS] (2.51) followed by *Peste des petits* ruminants [PPR] (2.22), black quarter [BQ] (1.89), foot-and-mouth disease [FMD] (1.71), theileriosis [TE] (1.70), enterotoxaemia [ET] (1.54), anthrax [AX] (1.48), sheep and goat pox [SGP] (1.44), rabies [RA] (1.39), babesiosis [BA] (1.38), bluetongue [BT] (1.31) and fasciolosis [FA] (1.27) based on mean R_0 values for Karnataka. The herd immunity threshold was high for HS [60.2%] followed by PPR [55.0%], BQ [47.1%], FMD [41.5%] and other diseases. The vaccination coverage required showed highest levels for HS, followed by PPR, BQ, FMD, TE, ET, etc. Thus, R_0 values may be used for prioritizing livestock diseases by policy makers and for planning the necessary preventive measures. The herd immunity threshold and vaccination coverage obtained for livestock diseases will help in allocating the scarce resources for vaccination effectively and to prevent livestock diseases outbreaks in Karnataka.

Keywords: Herd immunity threshold, Karnataka, Livestock diseases, Prioritization, R_0, Vaccination coverage

In India, the livestock diseases are an important factor affecting the production of animals and causes economic loss to livestock farmers. The basic reproduction number (R_0) is used to measure the transmission potential of a disease. In epidemiology, the R_0 denotes the average number of secondary cases of infectious diseases that one case would generate in a completely susceptible population and the rate is affected by many factors including rate of contacts in the host population, probability of infection being transmitted during contact and duration of infectiousness (Rothman 1998). Many studies have been conducted in the past by using different statistical analysis techniques to understand the various livestock diseases in India. These studies include meta-analysis of prevalence of subclinical, clinical and major mastitis pathogens in India was reported and identified the prevalence estimates for India and its different zones (Krishnamoorthy *et al*. 2017) and emphasized the importance of mastitis and major pathogens in dairy animals of India. In Tamil Nadu, the spatio-temporal epidemiological analysis identified the two agroclimatic zones, time period to take action and diseases which requires preventive measures for effective control of livestock diseases outbreaks in this state (Krishnamoorthy *et al.* 2016) and implied the importance of analysis of past livestock diseases outbreaks, which will help in the future prevention of livestock disease outbreaks. The periodic regression analysis of livestock diseases outbreaks revealed that there was cyclical nature of disease outbreaks for BQ, PPR, SGP, FA and TR with peak occurrence during every 4–5 years (Krishnamoorthy *et al*. 2019). The use of economic loss for prioritizing the livestock diseases may not be suitable in future planning and decision making by policy makers and various stakeholders. The R_0 values are available for various human diseases and no data or literature is available on R_0 values for livestock diseases in India. Hence, the present study was conducted to prioritize the livestock diseases based on the R_0 values obtained for every year by statistical methods during the period 2000 to 2018 and calculated the herd immunity threshold and vaccination coverage required by using R_0 values for the Karnataka.

MATERIALS AND METHODS

Livestock diseases outbreak data including year and month of outbreaks, number of clinically diagnosed cases,

*Corresponding author e-mail: P.Krishnamoorthy@icar.gov.in

number of death cases and number of susceptible animals were obtained for the period 2000–2018 from Department of Animal Husbandry and Veterinary Services, Government of Karnataka, Bengaluru. The thirteen livestock diseases included in this study were anthrax [AX], babesiosis [BA], bluetongue [BT], enterotoxaemia [ET], fasciolosis [FA], foot and mouth disease [FMD], haemorrhagic septicaemia [HS], *Peste des petits* ruminants [PPR], rabies [RA], sheep and goat pox [SGP], theileriosis [TE] and trypanosomosis [TY].

Estimation of R_0 value by various statistical methods: Different statistical methods were used for calculating the R_0 values as described earlier (Obadia *et al.* 2012). The statistical methods employed were Attack rate method, Exponential growth rate (Wallinga and Lipsitch 2007), Maximum likelihood estimation (White and Pagano 2008), Sequential Bayesian method and estimation of time dependent reproduction number as described earlier (Wallings and Teunis 2004). The analysis was done by using the R software version 3.5.2 with R_0 package, an open source software. During the estimation of R_0 values, if any method was returned with error, the results of next methods were considered, and maximum of the estimate was considered if all the method obtained the result estimates. The results obtained were expressed as the Mean±SE (standard error) and confidence interval (CI) at 95% level as described earlier (Snedecor and Cochran, 1980).

Estimation of herd immunity threshold (*HIT*): Herd immunity occurs when a significant proportion of livestock population (or the herd) has been vaccinated and provides the protection for the susceptible animals. More the number of animals vaccinated in the population, the lower is the likelihood that a susceptible animal (unvaccinated) would come into contact with the infection. It is more difficult for diseases to spread between individuals if large number of animals are immune already and chain of infection is broken. The herd immunity threshold is the proportion of animal population that needs to be immune in order for an infectious disease to become stable in the herd or population. If this is reached, by way of vaccination programmes, then each case leads to single new case and the infection will become stable within the livestock population, i.e. R_0=1. The HIT was calculated as described earlier (Fine *et al*. 2011) and as follows:

$$HIT=1-\frac{1}{R_0}$$

The value obtained can be used in the infectious disease control and vaccination programmes for various livestock diseases. The HIT was calculated for 13 livestock disease in Karnataka state using mean R_0 value.

Determination of vaccination coverage: R_0 can be used to determine the minimum vaccination coverage required for elimination of the diseases in the livestock population in a particular geographical area. From the herd immunity threshold which includes R_0 values, the minimum vaccination coverage (Vc) required for control or elimination of livestock diseases was calculated for Karnataka as reported earlier (Fine *et al*. 2011) and given by

$$Vc=\left(1-\frac{1}{R_0}\right)/Ve$$

where, Ve is the vaccine efficacy.

The vaccine efficacy usually varies with the different type of vaccines and also based on the livestock diseases, where vaccines were used. Hence, the vaccination coverage required for various livestock diseases was calculated based on R_0 values and the three scenarios of vaccine efficacy at 70, 80 and 90% levels were considered.

RESULTS AND DISCUSSION

The mean±SE R_0 values with confidence interval at 95% level for 13 livestock diseases during the period 2000–18 for Karnataka state are given in Table 1. There was variation in the R_0 values between the various livestock diseases. The livestock diseases were prioritized for high transmission potential as HS (2.51) followed by PPR (2.22), BQ (1.89), FMD (1.71), TE (1.70), ET (1.54), AX (1.48), SGP (1.44), RA (1.39), BA (1.38), BT (1.31) and FA (1.27). In large ruminants, the R_0 values were high for HS, BQ, FMD and in small ruminants for PPR, ET, SGP during the period under report in Karnataka. All the thirteen livestock diseases had the mean R_0 values above 1 indicating the potential of spread of infection from one animal to other animals in Karnataka.

Bacterial diseases: The bacterial diseases included for the study were AX, BQ, ET and HS. The AX outbreaks showed R_0values > 1 indicating the severity of the disease but however the disease revealed decreasing trend of R_0 values over the years, indicating the decreased in AX outbreaks and concurred with previous study (Krishnamoorthy *et al.* 2019). This might be due to the effective use of AX spore vaccine in the large and small ruminants in the endemic districts of Karnataka. Further, the preventive vaccination against AX has to be taken seriously in livestock, to decrease the R_0 value equal to 1. BQ showed variation in the R_0 values but the value became <1 during 2017 indicating the disease may not spread to other susceptible animals and having less impact on the livestock during recent years. This might be due to the effective vaccination followed against this disease in different parts of the Karnataka. However, the mean R_0 value showed 1.89 and acts as an important disease affecting large ruminants. The ET outbreaks were reduced and showed decreasing trend from the year 2000 to 2018. Based on R_0 values, this disease showed <1 for 4 years and indicating the less severity of this disease. If the current management strategies including vaccination against ET is continued to have the desired results in Karnataka and is in agreement with previous study (Krishnamoorthy *et al.* 2019). HS outbreaks showed the highest R_0 value of 21.49 during 2015 and also the mean R_0 value was 2.51. This indicated the importance of the HS outbreaks in the livestock in Karnataka and requires effective vaccination

Table 1. R_0 values for various livestock diseases occurred in Karnataka for the period 2000–2018

Year	Livestock diseases											
	AX	BA	BQ	BT	ET	FA	FMD	HS	PPR	RA	SGP	TE
2000	1.08	0.76	1.44	0.99	1.20	0.76	2.55	1.09	1.07	1.36	0.92	–
2001	1.23	–	2.93	1.75	4.84	1.97	2.63	1.17	–	1.15	1.29	–
2002	2.19	–	1.08	1.16	1.27	0.76	1.25	1.16	1.91	1.38	1.53	–
2003	1.37	–	2.98	1.43	2.01	–	2.98	1.13	10.55	2.13	1.51	–
2004	2.38	–	1.74	0.92	0.81	–	1.50	1.43	3.83	1.59	1.62	–
2005	1.72	–	1.67	1.14	1.91	–	2.98	1.63	2.22	–	1.00	–
2006	1.46	–	1.51	1.14	2.08	–	3.21	1.28	1.18	–	1.86	–
2007	1.31	–	1.35	1.62	1.22	–	1.38	1.64	1.27	0.76	1.05	–
2008	1.75	–	3.21	0.97	2.19	–	1.10	1.78	1.91	1.49	1.05	–
2009	1.50	–	1.4	1.29	1.27	–	0.81	1.80	1.10	1.09	1.23	–
2010	1.13	–	1.01	1.64	1.57	–	–	2.00	1.26	1.23	1.38	–
2011	1.94	–	3.33	0.78	0.97	–	–	1.51	1.85	1.33	3.72	–
2012	1.09	–	1.57	–	1.60	–	1.60	2.04	1.60	1.36	2.08	–
2013	1.62	–	2.90	2.08	1.26	–	1.68	1.32	1.54	–	1.67	–
2014	1.20	–	1.29	1.23	1.11	1.60	0.84	1.45	1.65	1.62	1.22	1.67
2015	1.23	1.78	2.63	2.24	1.26	–	1.33	21.49	3.74	1.39	0.79	1.64
2016	1.37	–	1.58	0.81	1.04	–	0.91	1.37	1.06	1.62	1.20	1.78
2017	1.27	–	0.90	1.67	0.76	–	0.99	0.89	1.15	–	1.10	–
2018	1.20	1.59	1.47	0.76	0.80	–	1.37	1.57	1.10	–	1.19	–
Mean ± SE	1.48± 0.09	1.38± 0.31	1.89± 0.19	1.31± 0.10	1.54± 0.21	1.27± 0.31	1.71± 0.20	2.51± 1.06	2.22± 0.53	1.39± 0.08	1.44± 0.15	1.70± 0.04
Confidence interval at 95% level	1.31– 1.64	0.76– 1.99	1.53– 2.25	1.11– 1.52	1.13– 1.94	0.67– 1.87	1.32– 2.10	0.44– 4.58	1.19– 3.25	1.23– 1.56	1.15– 1.73	1.61– 1.78

AX, Anthrax; BQ, Black quarter; BT, Bluetongue; ET, Enterotoxaemia; FMD, Foot and mouth disease; HS, Haemorrhagic septicaemia; PPR, *Peste des petits ruminants*; RA, Rabies; SGP, Sheep and goat pox; BA, Babesiosis; FA, Fasciolosis; TE, Theileriosis. For Trypanosomosis only one R_0 value 1.67 was available for the year 2015.

strategy to reduce the HS cases. Further, the findings from the present study concurred with the previous reports which indicated the higher case fatality rate for HS (Krishnamoorthy *et al.* 2016). The HS stands first in the mean R_0values when compared to other livestock diseases, and necessary preventive measures includes HS vaccination should be followed effectively to control the disease in Karnataka.

Viral diseases: The viral diseases included in this study were BT, FMD, PPR, RA, SGP. The BT showed the increase in R_0 values over the period and there was cyclical nature in the values occurring ≤1 for every four years. This observation in the present study concurred with the previous study on periodic regression analysis which showed the cyclical nature of the BT disease outbreaks in India (Krishnamoorthy *et al.* 2019). The FMD revealed the decreasing trend in the R_0 values over the years and less than 1 R_0 values occurred during 2009, 2014, 2016 and 2017. This finding from the present study might be due to the preventive measures including vaccination of adult animals twice annually under FMD control programme (FMD-CP) and biosecurity measures are being followed in Karnataka. The PPR showed R_0 values greater than one throughout the study period and concurred with previous study in Tamil Nadu, which indicated the higher prevalence rate per 1,000 small ruminant's population for PPR (Krishnamoorthy *et al.* 2016). Further, the period regression analysis of PPR outbreaks in India indicated that the disease will continue to occur beyond 2026 (Krishnamoorthy *et al.* 2019) and corroborated with the present study. The highest R_0 value for the PPR was 10.55 occurred in 2003 and correspond to more number of PPR cases, after which the PPR control programme was started and implemented in the Karnataka. The R_0 values for RA revealed >1 for the period under report except during the year 2007 (0.76). The SGP revealed cyclical pattern in the R_0 values during the period under report and corroborated with the previous study (Krishnamoorthy *et al*. 2019). There was no available literature to compare the findings from this study since no work on R_0 values for viral livestock diseases was carried out in India.

Parasitic diseases: The data on the parasitic disease cases were limited in our database during the period under study. The number of clinically diagnosed cases appear to be increased during 2013 to 2015 which may be due to the reporting of these diseases in National Animal Disease Reporting System (NADRS), a software to enter the diseases details online developed by Department of Animal Husbandry and Dairying, Government of India and also the availability of diagnostic facility in different diagnostic laboratories of State Animal Husbandry Departments (Krishnamoorthy *et al.* 2019). The highest R_0 value was 1.97 observed in FA during 2001 when compared to other parasitic diseases. These diseases will continue to occur at

the same level due to ineffective preventive measures adopted including vaccination, control of vectors, etc. To reduce these parasitic diseases occurrence in Karnataka, necessary preventive measures include deworming of young and adult animals twice a year, i.e. once before the onset of monsoon and during the monsoon. The necessary preventive measures to be undertaken in the animals under the field conditions by the veterinarians includes reducing the contact between the vectors and host, proper treatment strategies, regular screening of animals for parasitic diseases. There was no available literature to compare the findings from this study since no work on R_0 values for parasitic livestock diseases was carried out.

Herd immunity threshold: The herd immunity threshold (HIT) levels for the various diseases of livestock was calculated using R_0 values and are depicted in (Fig. 1). In the present study, the highest herd immunity threshold was required for HS (60.2%) followed by PPR (55.0%), BQ (47.1%), FMD (41.5%) and other livestock diseases. The higher the herd immunity levels were required for HS in large ruminants and PPR in small ruminants, since the R_0 values was higher indicating the more spread of infection between the contact animals. The HIT values indicate the percentage of animal population required to be immune against particular livestock diseases so as to prevent the spread of infection between the animals. The major constraints in the control of livestock diseases in the developing countries like India are poor vaccination coverage, lack of financial support and insufficient infrastructure, which interferes the building up of herd immunity (Swaminathan *et al.* 2016). The achievement of HIT levels by way of vaccination is required to the control the spread of infection from one animal to other animals and also to prevent the occurrence of the livestock diseases outbreaks.

Vaccination coverage: Vaccination coverage required for the 9 livestock diseases under three vaccine efficacy levels are given in Fig. 2. The parasitic diseases were not included

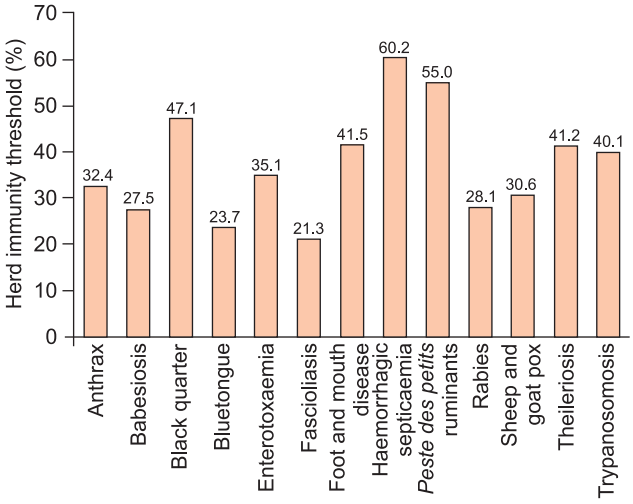


Fig.1. Herd immunity threshold levels for various livestock diseases based on the mean R_0 values in Karnataka.

in the calculation of vaccination coverage since no vaccines were available for use in the parasitic diseases. The three scenarios included in this study were 70, 80 and 90% of vaccine efficacy levels, since the exact vaccine efficacy or effectiveness was not known for all the livestock disease vaccines. In the present study, the vaccination coverage required were high for HS, PPR, BQ and FMD due to high R_0 values and these diseases require continuous efforts in the form of preventive vaccination to be undertaken to reduce the occurrence of livestock outbreaks and also to decrease the R_0 values. The vaccination coverage required depends on the vaccine efficacy, which indicates the animals given vaccine or the animals are immune for the particular disease. Further, the vaccine efficacy depends on the type of the vaccines, time of vaccination, duration of immunity and vaccination programme followed in the animals. The vaccination coverage required will be more, if the vaccine efficacy was less and was inversely related to each other.

Based on the R_0 values, the livestock diseases may be

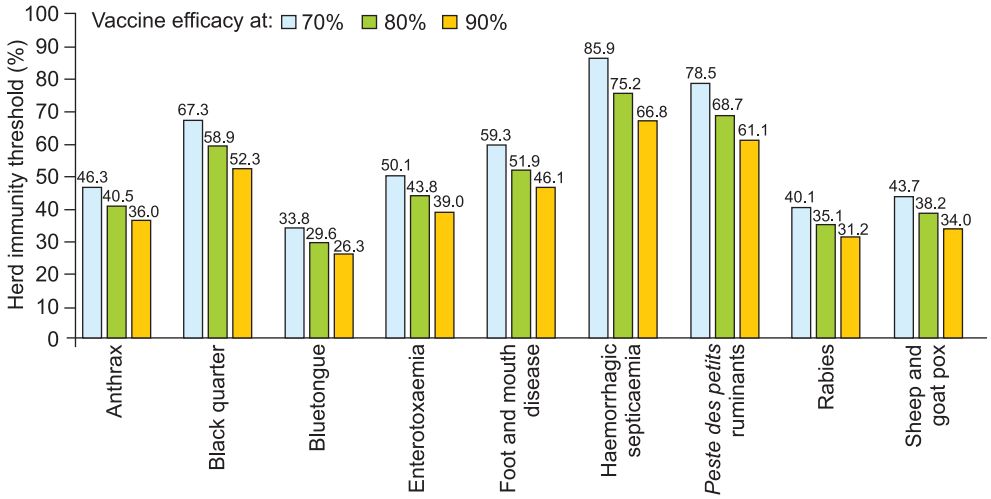


Fig. 2. Vaccination coverage for the various livestock diseases at different vaccine efficacy levels (70, 80 and 90%) based on R_0 values in Karnataka.

prioritized for taking necessary preventive measures in the Karnataka and should be considered with other factors including the economic losses, disease burden, socio-economic factors by policy makers and other stake holders. The livestock disease outbreaks showed decreasing trend over the years and it indicated the efforts undertaken by various vaccination programmes are bearing fruits in India (Krishnamoorthy *et al.* 2019) and concurred with the present study. Improved monitoring and/or surveillance, rapid and confirmatory diagnosis, and networking of diseases are required to go forward in the path of livestock diseases eradication. Good management practices like stringent biosecurity measures, strict sanitation and hygiene practices in the farm, isolation and quarantine of diseased animals, and trade restrictions are necessary for successful operation of control programmes (Swaminathan *et al.* 2016). Vaccination is the main strategy for control and eradication of many livestock diseases in India. Further, there should be continuous epidemiological analysis of livestock disease outbreaks to be undertaken to devise strategies in preventing these diseases in Karnataka. The limitations in the present study was the availability of livestock diseases outbreak data, since there may be under-reporting and non-reporting of livestock diseases in the Karnataka during the period under report which may influence the R_0 values. To the best of our knowledge, this was the first report of R_0 values, herd immunity threshold levels and vaccination coverage required for various livestock diseases for Karnataka state. Thus, the R_0 values obtained for four bacterial, five viral and four parasitic diseases will be helpful in prioritizing the diseases for preparing strategies for planning the preventive measures, allocation of scarce resources effectively, and the herd immunity threshold levels, vaccination coverage required for various livestock diseases in Karnataka. HS, BQ, FMD in large ruminants and PPR, ET in small ruminants are the major livestock diseases of importance in Karnataka which requires constant and continued efforts for control and prevention of these diseases in livestock. The livestock diseases which need to be taken on priority for prevention was known by this analysis and helps the policy makers and stakeholders for making well informed decisions.

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