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Trends and future prediction of livestock diseases outbreaks by periodic regression analysis

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ABSTRACT

Livestock disease outbreaks become a burden to the animal husbandry farmers and cause great economic loss in India. Period regression analysis is used to find the periodic or cyclic character of livestock disease outbreaks in animals, as many other natural phenomena in environment is periodic or cyclic in nature. In present study, livestock disease outbreaks of anthrax (AX), black quarter (BQ), enterotoxaemia (ET), haemorrahgic septicemia (HS), bluetongue (BT), foot-and-mouth disease (FMD), *peste des petits* ruminants (PPR), sheep and goat pox (SGP), babesiosis (BA), fasciolosis (FA), theileriosis (TH) and trypanosomosis (TR) were analyzed using periodic regression to know the trend and future prediction of outbreaks. Time series data on disease outbreaks, month and year was collected from National Animal Disease Referral Expert System database for 2001–2016. The regression curves were prepared with baseline, observed outbreaks and upper bound curves for 12 livestock diseases. The analysis revealed decreasing trend for AX, BQ, ET, HS, FMD, PPR, SGP and a cyclical trend of peak occurrence for every 4–5 years was observed in BQ, PPR, SGP, FA and TR. However, TR showed increasing trend and BT, BA, FA, TH outbreaks were maintained at the same trend in the past and future also. Further, BQ in 2026, ET in 2020, HS in 2022, FMD in 2023, outbreak numbers may touch the zero point, if the preventive measures are continued for these diseases effectively. Thus, continuous and constant efforts are needed for prevention of livestock diseases outbreaks from all stakeholders, which will improve the economy of farmers in India.

Key words: Future prediction, Livestock diseases, Outbreaks, Periodic regression, Trend

Many biological, agricultural and livestock disease data are characterized by seasonal variations. Periodic phenomena is primarily close not only to biological data, but to non-biological data also. Periodic or cyclic phenomena are characteristic of many different types of data, which are synchronized with daily, lunar, or annual changes (Bliss 1970). The data following periodic or cyclical behaviour are often encountered, especially in agriculture (Cobanovic *et al*. 2006). Many kinds of agricultural data tend to fluctuate at regular time intervals and also showing characteristic of periodic nature (Little and Hills, 1978). The periodic or cyclic character of phenomena's in nature is expressed in time and space. The earlier report indicated that the biological cycles may be divided into two, i.e. which depend on physical environment and those which do not depend on physical environment (Bliss, 1970). In the first category, the biological phenomenon is determined physiologically. In the second category, the cycles depend on many other potential risk factors, which can modify or change the biological phenomena. Meta-analysis of prevalence of subclinical, clinical and major mastitis pathogens in India was reported and identified in difference zones in India (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 zones and diseases which require preventive measures for effective control of livestock disease outbreaks (Krishnamoorthy *et al.* 2016).

Livestock disease outbreaks, affects the economy of the animal husbandry farmers in India. Analysis of previous disease outbreaks will help in future planning of the control and preventive measures effectively. An effective management for emerging and re-emerging diseases needs multidisciplinary activities like surveillance, rapid reporting, collection and transport of clinical materials for diagnosis of the etiological agents, strengthening of basic research, epidemiological modeling and prediction, forecasting model development, development of novel vaccine candidates and suitable adjuvant, etc. (Biswal *et al*. 2012). The livestock diseases may occur in seasonal and cyclical pattern in animals, if it is known by statistical analysis methods, it will help in effective utilization of available resources in planning the preventive measures.

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No literature is available on the periodic regression analysis of livestock disease outbreaks in India. The trend pattern of livestock disease outbreaks will guide us whether the disease outbreaks are increasing or decreasing over a period of time and to ascertain the effectiveness of various vaccination programmes carried in India. Based on the past pattern of livestock disease outbreaks future outbreaks can be predicted by using prediction analysis. Hence, the present study was carried to analyse the livestock disease outbreaks occurred in India for the period 2001–2016 by using periodic regression analysis. This will help to know the trend pattern and future prediction of the diseases.

MATERIALS AND METHODS

The month wise data on 12 livestock disease outbreaks were collected from the National Animal Disease Referral Expert System (NADRES) database available at National Institute of Veterinary Epidemiology and Disease Informatics, Bengaluru, Karnataka which contains the livestock diseases outbreak data collected every month from all the states in India during 2001–2016. The data was segregated into bacterial, viral and parasitic diseases, each four in number, viz. anthrax [AX], black quarter [BQ], enterotoxaemia [ET], haemorrahgic septicemia [HS], bluetongue [BT], foot-and-mouth disease [FMD], *peste des petits* ruminants [PPR], sheep and goat pox [SGP], babesiosis [BA], fasciolosis [FA], theileriosis [TH] and trypanosomosis [TR]. The months were coded in numbers 1 to 12 and outbreak numbers were arranged in Microsoft excel for periodic regression analysis. In the analysis of the periodicity in the time series data, the important determinants were the length of the cycle or fundamental period, its amplitude or the range from the minimal to the maximal response and angular point in time during the periodic cycle when the response is maximal (Bliss, 1970). These parameters were easily estimated by using many statistical softwares.

A time series data or an outbreak Y_t (t =1, ..., N) observed at equal intervals of time was expressed as

$$Y_t = \hat{Y}_t + \varepsilon_t,$$

where $\hat{Y}_t$ is unobserved fixed value at time t and $\{\varepsilon_t\}$ is a sequence of random errors identically and independently distributed with expectation 0 and variance σ^2. To determine variability of the livestock disease outbreaks data whether it has periodic components, the series was approximated by finite Fourier series of the form, if the number of data was even N=2n,

$$\hat{Y}_t = A_0 + 2\sum_{m=1}^{n-1}(\text{Am}\cos 2\pi \text{mf1t} + \text{Bm}\sin 2\pi \text{mf1t}) + \text{An}\ \text{Cos}2\pi \text{nft1}$$

or if the number of data was odd: N= 2n–1

$$\hat{Y}_t = A_0 + 2\sum_{m=1}^{n-1}(\text{Am}\cos 2\pi \text{mf1t} + \text{Bm}\sin 2\pi \text{mf1t})$$

Here $R_{m=}\ \sqrt{(A_m^2+B_m^2)}$ is the amplitude, and φ_m=arctg (B_m/A_m) is the phase of the i-th component. The $\hat{Y}_t$ function was in linear manner with combination of functions sinus and cosinus along with frequencies, which was proportional to the frequencies f_1 =1 N, so it became the linear multiple regression with regressors as sinus and cosinus functions.

$$\text{Since}\ \frac{1}{N}\sum_{t=1}^{N} y_t^2 = R_0^2 + 2\sum_{m=1}^{n-1} R_m^2 + R_n^2$$

contribution of i-th harmonical component to the mean of the total sum of squares of time series is equal to R_i^2, the periodic regression analysis was calculated as reported earlier by Èobanoviæ and Luèiæ (1992). By calculating the mean of total sum of squares, it was possible to single out harmonical components which describe the time series data as well. The periodic regression analysis was carried out by using R software version 3.2.2 CRAN (Comprehensive R Archive Network) and the statistical values for significance was based on P value and the regression curves were obtained.

RESULTS AND DISCUSSION

The detailed periodic regression analysis values of 12 livestock diseases for the period 2001–2016 are given in Table 1. Most of the livestock diseases showed the significance for intercept, X value, sinus and cosinus values and are given in the Table 1. The results of the present study concurred with the previous report for the periodic regression analysis (Èobanoviæ and Luèiæ, 1992). Four bacterial, viral and parasitic diseases were analyzed for trends of the disease and predicted the future disease outbreaks for the period from 2017–2026. The periodic regression analysis curve showed the baseline of the outbreaks, upper bound line which was 95% confidence interval from the baseline and the observed line indicated the actual outbreaks occurred during 2001–2016 in different months in a calendar year.

Bacterial diseases: The bacterial diseases included for the study were AX, BQ, ET and HS. The trend pattern and prediction curves of AX and BQ are given in Fig. 1. The AX outbreaks showed 55 outbreaks during 2001 and reduced to 20 outbreaks during 2016. The trend analysis revealed that the AX outbreaks are decreasing slowly, but outbreaks were reported continuously every year in India. This might be due to the effective use of AX spore vaccine in the large and small ruminants. The observed outbreaks curve revealed that many a times it has crossed the upper bound curve and indicated the epidemic nature of this disease in livestock over the period. Further, the preventive vaccination against AX has to be taken seriously in livestock, since AX outbreaks will continue to occur beyond 2026 also as per the prediction curve. BQ periodic analysis curve revealed a fast decreasing trend in the outbreak numbers from 100 outbreaks in 2001 to 12 outbreaks in 2016, and the outbreaks, i.e. baseline will touch the zero point during 2026 based on the prediction analysis. This might be due to the effective vaccination followed against this disease in different parts of the country and the current strategies should be continued for controlling the BQ in livestock. The baseline and upper bound curve for AX and BQ revealed a cyclical pattern of increasing outbreaks for

Table 1. Periodic regression analysis values of livestock disease outbreaks in India for 2001–2016

Disease	Parameter	Estimate	Standard Deviation	t value	P value	R value	R^2	Adjusted R^2
Bacterial diseases								
Anthrax	Intercept	9.849	0.701	14.05	<0.001**	0.40499	0.16402	0.14784
	x	–0.026	0.006	–4.357	<0.001**			
	c1	–1.295	0.411	–3.153	0.002**			
	s1	0.392	0.419	0.936	0.351^{ns}			
Black Quarter	Intercept	39.211	2.031	19.307	<0.001**	0.53862	0.29012	0.27638
	x	–0.121	0.018	–6.862	<0.001**			
	c1	3.293	1.228	2.682	0.008**			
	s1	0.669	1.352	0.495	0.621^{ns}			
Enterotoxaemia	Intercept	21.72	1.404	15.472	<0.001**	0.55304	0.30586	0.29242
	x	–0.099	0.012	–8.178	<0.001**			
	c1	–2.384	0.919	–2.595	0.01*			
	s1	–1.087	0.953	–1.141	0.256^{ns}			
Haemorrhagic Septicemia	Intercept	58.643	3.269	17.94	<0.001**	0.56827	0.32294	0.30984
	x	–0.237	0.028	–8.428	<0.001**			
	c1	0.958	2.009	0.477	0.634^{ns}			
	s1	–0.578	2.101	–0.275	0.784^{ns}			
Viral diseases								
Bluetongue	Intercept	4.133	0.891	4.637	<0.001**	0.17655	0.03117	0.01242
	x	–0.015	0.008	–1.91	0.058^{ns}			
	c1	–0.919	0.605	–1.519	0.131^{ns}			
	s1	0.205	0.62	0.33	0.742^{ns}			
Foot-and-mouth disease	Intercept	100.715	6.983	14.422	<0.001**	0.45890	0.21059	0.19531
	x	–0.386	0.061	–6.382	<0.001**			
	c1	–2.359	4.429	–0.533	0.595^{ns}			
	s1	–0.844	4.625	–0.183	0.855^{ns}			
Peste des petits ruminants	Intercept	29.925	1.985	15.074	<0.001**	0.38974	0.1519	0.13538
	x	–0.084	0.017	–4.812	<0.001**			
	c1	–4.429	1.321	–3.354	0.001**			
	s1	1.472	1.301	1.132	0.26^{ns}			
Sheep and Goat Pox	Intercept	2.066	0.715	2.889	0.004**	0.56427	0.3184	0.3052
	x	0.045	0.007	6.829	<0.001**			
	c1	3.337	0.52	6.424	<0.001**			
	s1	1.442	0.527	2.739	0.007**			
Parasitic diseases								
Babesiosis	Intercept	9.081	1.356	6.695	<0.001**	0.43747	0.19138	0.17573
	x	–0.023	0.013	–1.719	0.088^{ns}			
	c1	0.153	0.896	0.171	0.865^{ns}			
	s1	5.282	1.016	5.197	<0.001**			
Fasciolosis	Intercept	12.089	1.897	6.372	<0.001**	0.53005	0.28095	0.26703
	x	–0.023	0.018	–1.288	0.2^{ns}			
	c1	–2.437	1.263	–1.93	0.055^{ns}			
	s1	9.711	1.343	7.23	<0.001**			
Theileriosis	Intercept	6.977	0.845	8.262	<0.001**	0.29764	0.08859	0.07095
	x	–0.015	0.008	–1.94	0.054^{ns}			
	c1	0.245	0.547	0.448	0.655^{ns}			
	s1	1.803	0.608	2.966	0.003**			
Trypanosomosis	Intercept	30.396	7.067	4.301	<0.001**	0.47998	0.23038	0.20188
	x	–0.16	0.049	–3.264	0.002**			
	c1	–8.242	1.82	–4.528	<0.001**			
	s1	2.536	1.18	2.149	0.035*			

^{ns}Nonsignificant; *Significant at 95% level ($P<0.05$); **Significant at 99% level ($P<0.01$).

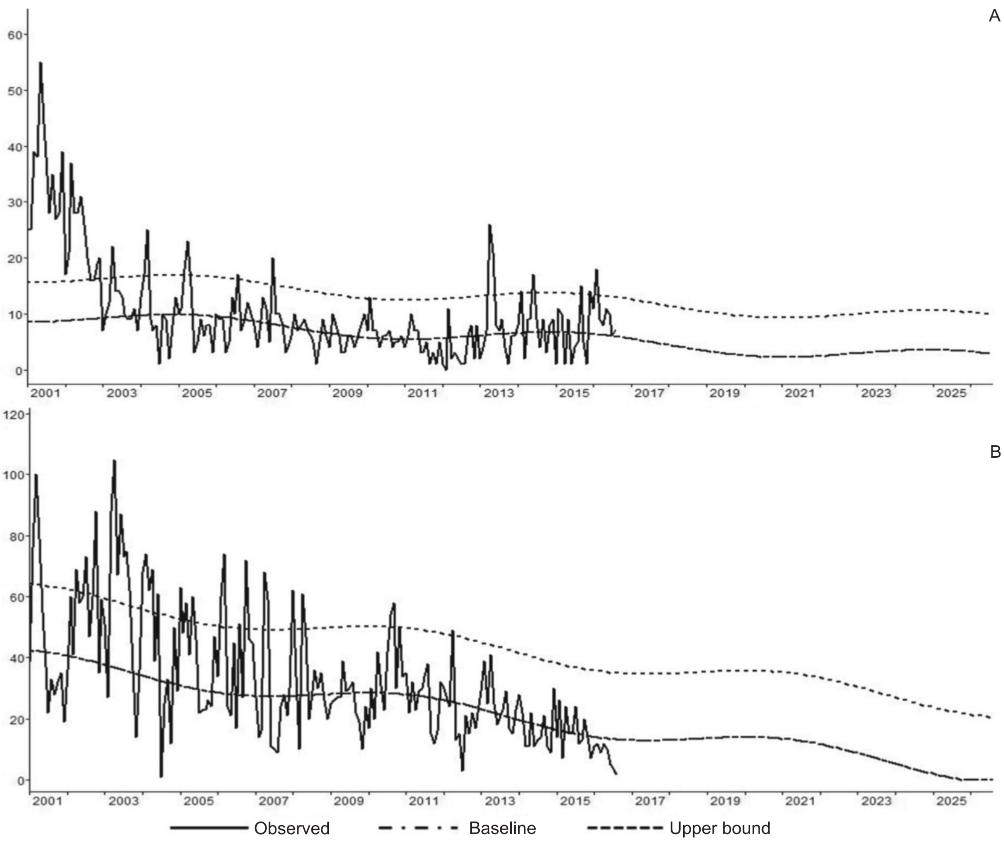

Fig. 1. Periodic regression analysis of bacterial disease outbreaks–anthrax (**A**) and black quarter (**B**).

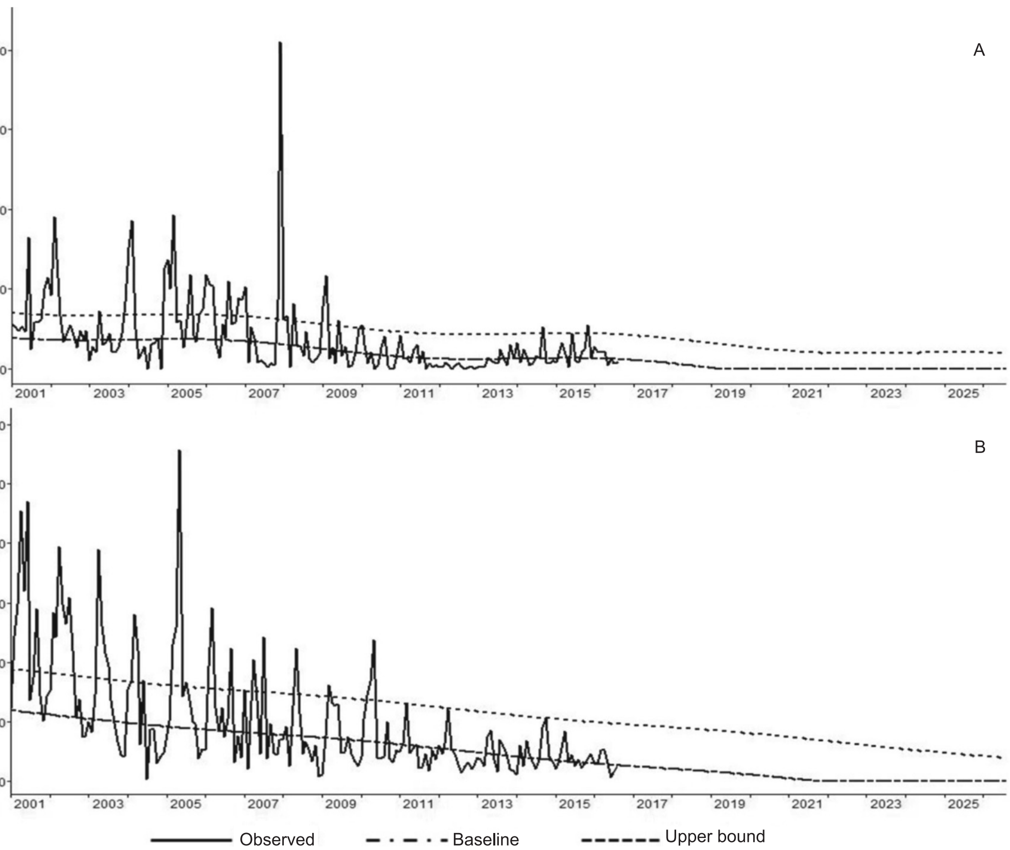

Fig. 2. Periodic regression analysis of bacterial disease outbreaks–enterotoxaemia (**A**) and haemorrhagic septicemia (**B**).

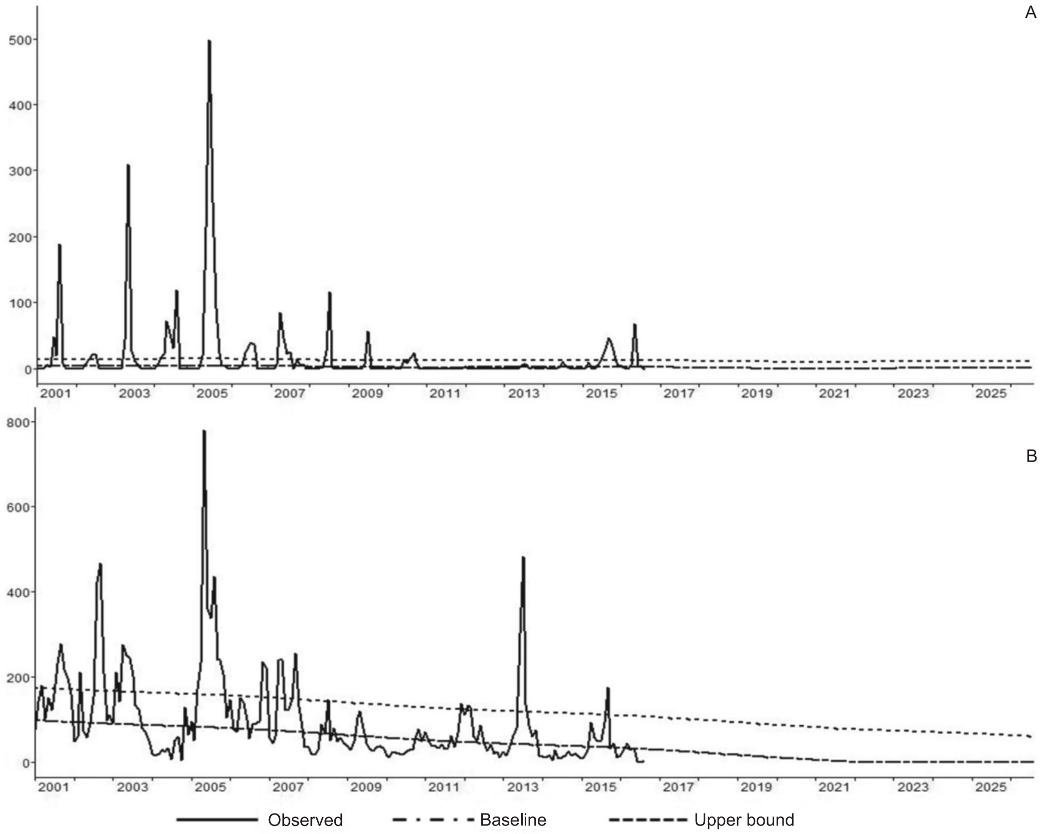

Fig. 3. Periodic regression analysis of viral disease outbreaks–bluetongue (**A**) and foot-and-mouth disease (**B**).

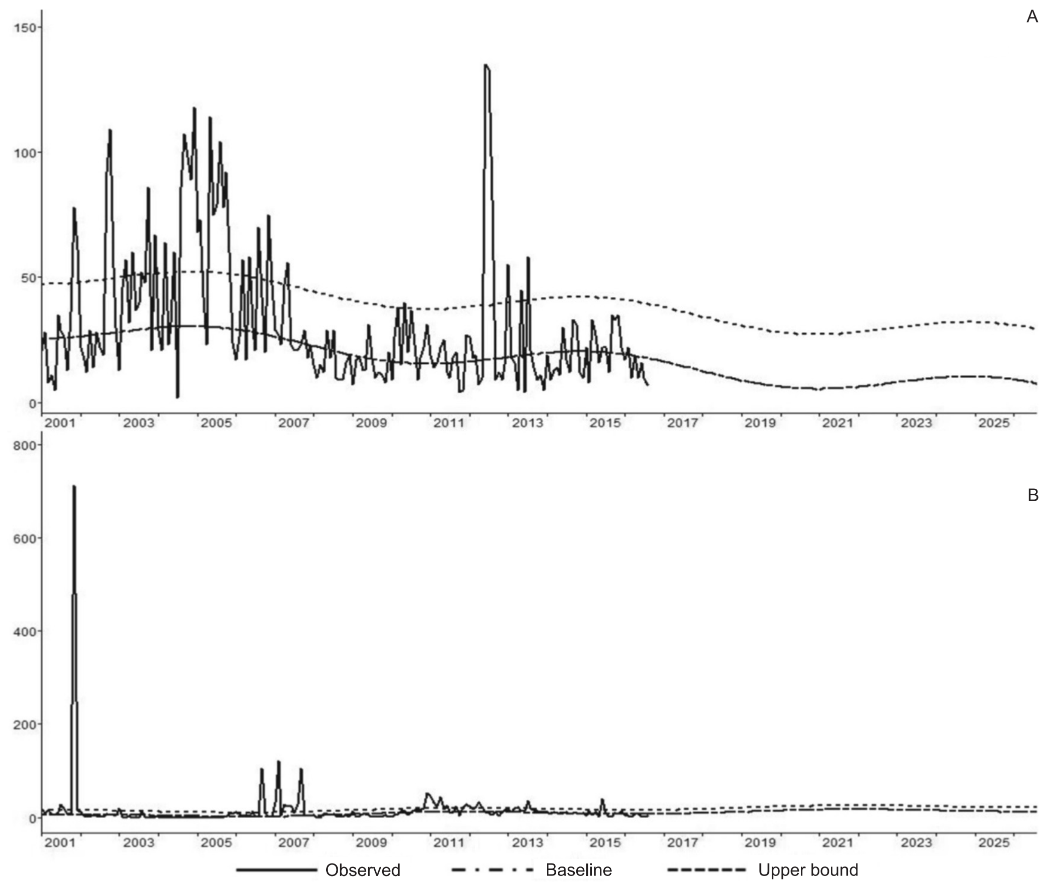

Fig. 4. Periodic regression analysis of viral disease outbreaks–*pesti des petits* ruminants (**A**) and sheep and goat pox (**B**).

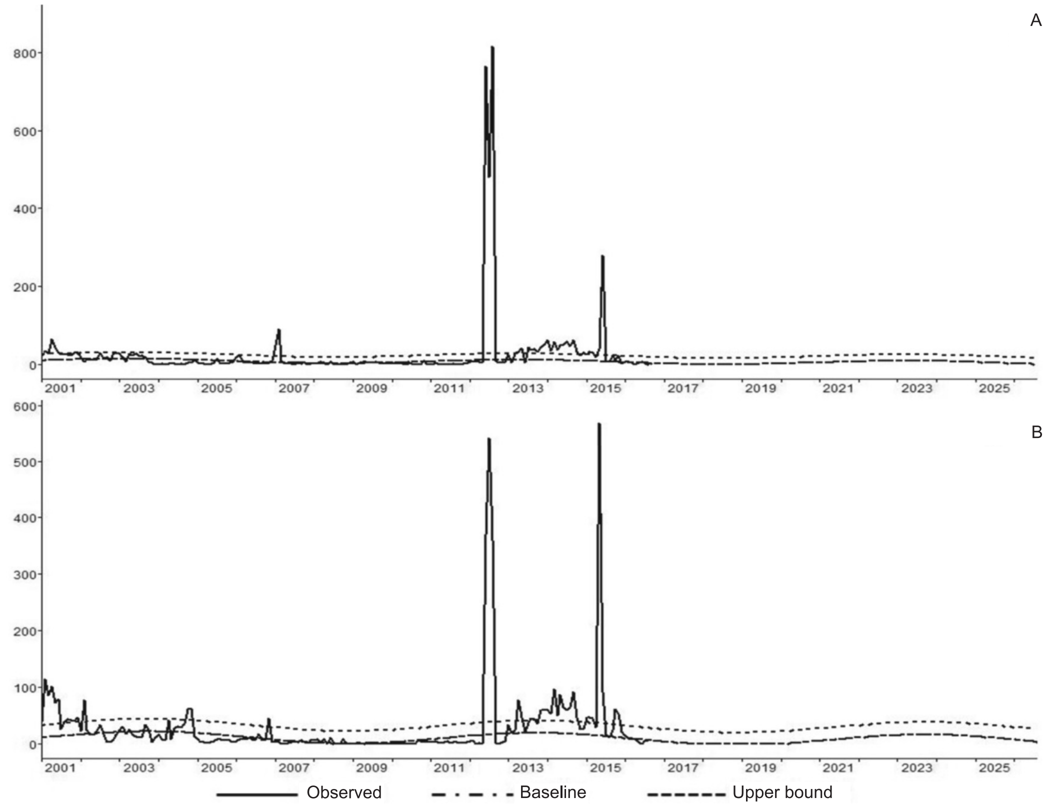

Fig. 5. Periodic regression analysis of parasitic disease outbreaks–babesiosis (**A**) and fasciolosis (**B**).

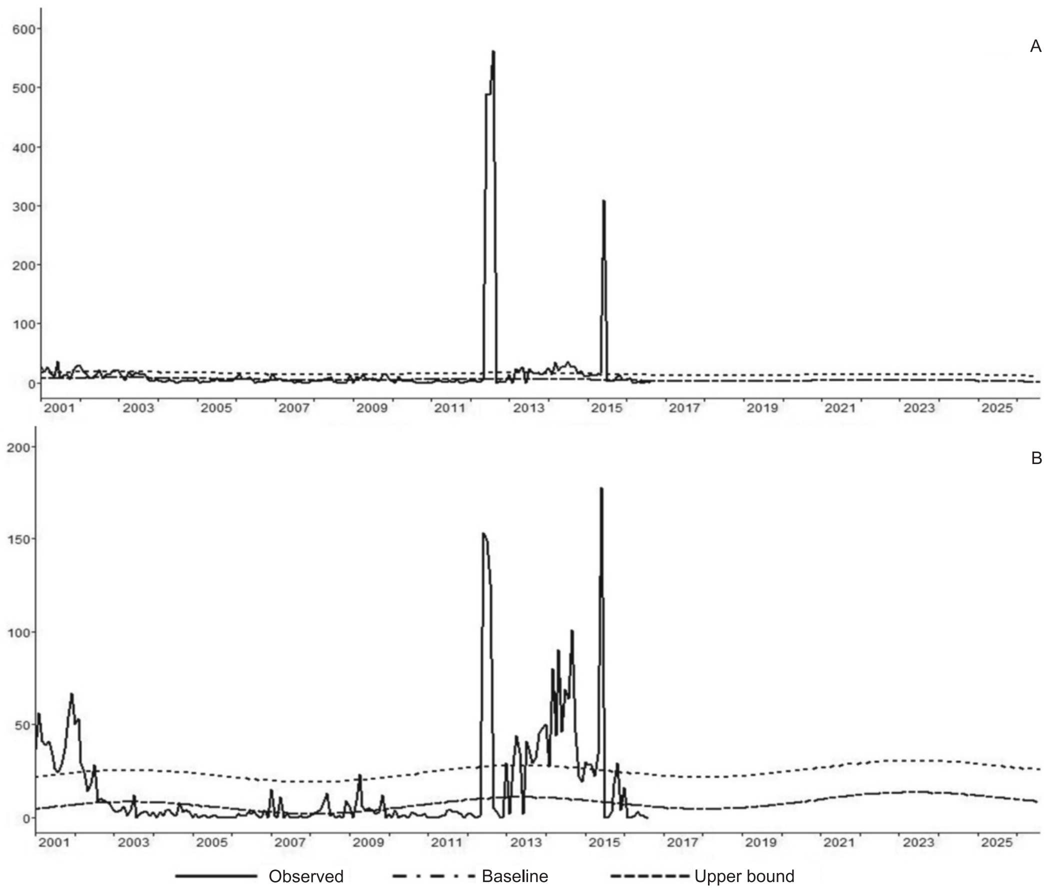

Fig. 6. Periodic regression analysis of parasitic disease outbreaks–theileriosis (**A**) and trypanosomosis (**B**).

every 4–5 years. This may be due to the time required for the pathogen to establish the disease in the desired host and to become an epidemic of severe nature. The results from the present study concurred with the previous report (Krishnamoorthy *et al.* 2016) which indicated the importance of AX vaccination in the two zones identified in Tamil Nadu based on the epidemiological analysis. The trend pattern and future prediction of ET and HS are given in Fig. 2. The ET outbreaks were reduced and showed decreasing trend from 200 outbreaks during 2008 to 10 outbreaks in 2017. Based on prediction analysis, ET outbreaks would touch the zero point during 2020, if the current management strategies like vaccination against ET was continued to have the desired results. HS outbreaks also showed the decreasing trend in the number of outbreaks that occurred recently when compared to past outbreaks during 2001. This might be due to availability of HS vaccine, continuous and regular vaccination in livestock under field conditions. Prediction analysis indicated that the HS outbreaks baseline will touch zero on 2022 and the HS vaccination, preventive measures should be followed effectively to control the disease in India.

Viral diseases: The periodic regression curves for BT and FMD are depicted in Fig. 3. The BT outbreaks maintained same trend continuously as in the past, but FMD showed decreasing trend showing that the baseline of outbreaks will become zero by 2003. This may be due to the preventive measures like vaccination of adult animals for two times annually under FMD control programme (FMD-CP). However, this is only prediction and may be true if the efforts are continued at the same level in future also. The trend and prediction curve for PPR and SGP are given in Fig 4. The PPR and SGP showed the decreasing trend in the outbreak numbers during the period under report and may be due to the PPR control programme and vaccination against SGP under field conditions. The findings from the present study concurred with previous report of FMD and PPR (Krishnamoorthy *et al.* 2016). The PPR and SGP outbreaks showed cyclical pattern of peak occurrence for every 4–5 years duration. This might be due to the circulation of virus in the animals and time required for the virus to become virulent and infectious, causing epidemics in India. However, these two diseases will continue to occur beyond 2026 also, which indicate the necessity of increasing the efforts to prevent these diseases in future. There was no available literature to compare the findings from this study since no work on periodic regression analysis of livestock disease outbreaks was carried out.

Parasitic diseases: The periodic regression curves of BA and FA are depicted in Fig. 5 and revealed the same pattern of outbreaks continuously. The outbreak numbers appear to be increased during the year 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 and also the availability of diagnostic facility in different diagnostic laboratories of State Animal Husbandry Departments. These diseases will continue at the same level due to no effective preventive measures adopted like vaccination, control of vectors, etc. The details of the trend and prediction of TH and TR are given in Fig 6. The TH revealed same pattern continuously but TY was slightly increased over the period of time. The TR outbreaks reported were more during 2013–2015 period when compared to the past year outbreaks. It might be due to the availability of diagnostic facilities and also non availability of preventive vaccines for these disease and vector control measures. To reduce the parasitic diseases occurrence, necessary preventive measures need to be undertaken in the animals under the field conditions by the Veterinarians like reducing the contact between the vectors and host, proper treatment strategies, and regular screening of animals for haemoprotozoan parasitic diseases.

The major constraints in the control of livestock diseases in the developing country like India are poor vaccination coverage, lack of financial support and insufficient infrastructure, which interferes with the building of herd immunity (Swaminathan *et al*. 2016). However, the livestock disease outbreaks showed decreasing trend over the years and it indicated that the efforts undertaken by various vaccination programmes are bearing fruits in India. Improved monitoring and/or surveillance, rapid and confirmatory diagnosis, and networking of diseases are required to go forward in the path of diseases eradication. Vaccination is the main strategy for control and eradication of many livestock diseases in India. 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). The spatio-temporal epidemiological analysis of past data on livestock disease outbreaks in Tamil Nadu identified the two zones and time period to undertake preventive measures as reported (Krishnamoorthy, *et al*. 2016). Further, continuous epidemiological analysis of livestock disease outbreaks needs to be undertaken for shorter period of time to modify the required strategies in preventing the livestock disease outbreaks in India.

Thus, the periodic regression analysis of bacterial, viral and parasitic diseases will help in knowing the trends, prediction of future outbreaks and assist in planning the preventive measures, allocation of scarce resources effectively. The BQ, HS and FMD, the major diseases of livestock will reach zero point, if the constant and continued efforts are undertaken for these diseases. The livestock diseases which need to be taken on priority for prevention were known by this analysis and helps the policy maker for making informed decisions. This is the first report of periodic regression analysis of livestock disease outbreaks in India to the best of our knowledge.

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