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Outbreak Prediction of Anthrax in Karnataka using Poisson, Negative-Binomial and Zero-Truncated Models

Statistic

KEYWORDS: Anthrax, Remote sensing, Zero-truncated model, Risk map

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ABSTRACT

Anthrax is a well-known zoonotic disease caused by Bacillus anthracis, a gram positive, spore forming aerobic bacteria. In livestock Anthrax is usually peracute and highly fatal whereas in humans it is a subacute disease and fatal if not treated immediately. Anthrax is prevalent world-wide and is one of the top ten livestock diseases in India and hence forecasting the outbreak of this disease by modelling is very helpful in saving the livestock and thereby averting economic loss to the livestock farmer in particular and country in general. In this paper, the data on the outbreak reports of Anthrax in livestock in Karnataka from 2000 to 2014 have been analysed. To develop the model, in the risk factor domain, amount of rainfall, temperature, soil pH, soil type and soil nutrients were collected retrospectively. Further, remote sensed variables like Normalized Difference Vegetative Index (NDVI) and Land surface temperature (LST) were collected using Moderate Resolution Imaging spectro-radiometer (MODIS) tools. Prediction models of anthrax outbreaks in Karnataka using count models viz. Poisson, Negative Binomial and Zero truncated models were developed. Initially, prediction models were tested for goodness-of-fit using Chi-square test. Then the models were evaluated using Akaike information criterion (AIC), AIC for correction (AICC) and Baysian Information Criterion (BIC). Zero-Truncated Poisson model provided the best fit for the data on taluk level outbreak of Anthrax. An attempt is made to explain how various factors influence outbreak of Anthrax. A risk map forecasting the outbreaks of Anthrax at taluk level was also generated.

Introduction

Anthrax is a neglected zoonotic disease caused by *Bacillus anthracis*, a gram positive, spore-forming, rod-shaped aerobic bacterium that affects mainly herbivores animals, although some wild mammals are also susceptible to it. Humans and carnivores are accidental hosts to Anthrax. The disease in livestock is usually per acute, characterized by septicaemia and sudden death in 1-3 hours with exudation of unclotted tarry coloured blood from natural orifices, incomplete rigor mortis and splenomegaly in cattle (Parker *et al.*, 2005). Anthrax is readily transmitted from animals to human beings via inhalation of spores, handling of infected animals, consumption of contaminated meat, contaminated carcass, contaminated fomites etc. An estimated 20,000 to 100,000 cases occur in humans worldwide per year, mostly in developing countries (Turnbull, 2008). Anthrax is a seasonal disease. An outbreak of Anthrax in an enzootic area occurs usually after a prolonged hot dry spell, which in turn was preceded by heavy rains or with rain ending a period of drought (Md. Saiful Islam *et al* 2013)

Anthrax is widely prevalent in many parts of Eastern Europe, Southern Europe, Africa, South America, Central Asia and South East Asia including India(Turnbull, 2008) It is one of the top ten livestock diseases reported from India(PD_ADMAS technical bulletin.2012.) Though it is prevalent throughout India, its higher endemicity in south India is attributable to warm humid climate, alkaline calcareous soil favouring survival and germination of anthrax spores. Indian economy is losing millions of dollars annually due to Anthrax in terms of heavy mortality, reduced livestock production, restriction in international trade of livestock and livestock products. Apart from its natural occurrence, *B. anthracis* remains as an appealing biological weapon (Inglesby *et al.*, 2002; Wang and Roehrl, 2005).

Materials and Methods

Data Collection

Data on outbreak of Anthrax in villages of Karnataka for the period 2000 to 2014 was obtained from the department of Animal Husbandry and Veterinary Services, Government of Karnataka. The collected data was later classified into district, taluk, and village based on the month and year of occurrence of the outbreaks.

Data description

Perusal of literature on Anthrax shows that factors like atmospheric temperature, rainfall, vegetation, soil type and soil nutrients play major role in the outbreak of the disease. To supplement these risk factors, remote sensing data were also collected. Remote sensing is a technique of obtaining data about the Earth's land or water surfaces without coming directly in contact with it, with the help of emitted or reflected electromagnetic energy. A source of electromagnetic radiation is transmitted from the source by the remote sensor mounted on a satellite to the surface on the Earth. After the interaction of radiation with the Earth's surface, it is transmitted back to the satellite mounted sensor. The sensor data is then transmitted to a ground station, where it is processed for analysis. This processed data is used for variety of applications.

The remote sensing variables *viz.,* Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) were included in the study. A database was generated for all the villages in Karnataka where Anthrax has been reported. A lag period of one month was also considered and LST, NDVI were measured. Amount of rainfall and soil nutrients in these villages were also studied.

LST and NDVI

The data on LST and NDVI were collected using satellite sensor from Moderate Resolution Imaging spectro-radiometer tools (MODIS Tools) aboard the Terra satellite. The daytime LST 8-day data was obtained from MODIS LST product MOD11A2. The NDVI 16-day data were obtained from MODIS NDVI product MOD13A1. The Hierarchical Data Format (HDF) file obtained was imported into MODIS tool and converted as Tag Image File Format(TIFF) file. Then, this TIFF file was imported into Erdas Imagine® software and was processed to get the pixel value.

Land Surface Temperature (LST) is the measure of radiative surface temperature of the Earth in a particular location. Land surface temperature measure is not the same as the air temperature measure. It depends on the vegetation cover and the soil moisture. Normalized Difference Vegetation Index (NDVI) is an index which measures the extent of greenness of plants or photosynthetic activity.

Negative values of NDVI (values approaching -1) indicate deep water. Values close to zero (-0.1 to 0.1) usually corresponds to barren areas of rock, sand, or snow. 0.1 to 0.2 corresponds to sand. Low, positive values represent shrub and grassland (approximately 0.2 to 0.4), high values are an indication of temperate and tropical rainforests (values approaching 1). The typical range is between -0.1 (for a not very green area) to 0.6 (for a very green area).

Statistical analysis

There are situations where the outcome variable is numeric and Normally distributed, or binary in nature. In certain situations the outcome variable is numeric, but in the form of counts. Usually, it is a count of rare events such as the number of outbreaks of a particular disease occurring in a population over a certain period of time. The aim of regression analysis in such instances is to model the dependent variable as the estimate of outcome using some or all of the explanatory variables using what are known as Count Models.

There are various Count Models, of which, Poisson model, Negative Binomial model, Zero truncated Poisson and Zero truncated Negative Binomial models have been used to develop the Anthrax outbreak model in the present study due to the fact that these models have the flexibility and power of parametric models, handling repeated measures, multiple covariates and various configurations of fixed and mixed effects, while assuming that the outcome has different distribution than the Normal distribution.

Poisson regression model requires the data distribution to be equal-dispersed i.e., the conditional variance equals the conditional mean. Negative binomial distribution is widely used in situations where data display over-dispersion i.e., conditional variance exceeds the conditional mean. Many count variables are often truncated. Zero truncated situations occur when observations enter the sample only after the first count occurs. That means the response variable cannot take the value zero. In such situations, Zero truncated models are applied.

Poisson Model

Poisson distribution assumes the equality of the conditional mean and the conditional variance i.e., equi-dispersion of data.

The probability mass function of a Poisson distribution is

$$P_{poi}(Y_i = y_i|x_i) = \frac{e^{-\mu_i}\mu_i^{y_i}}{y_i!}, \quad y_i = 0,1,2,\ldots$$

With mean and variance given by

$$E(y_i|x_i) = V(y_i|x_i) = \mu_i = exp(x_i'\beta)$$

$$\text{Log}\,(\mu_i) = x_i'\beta$$

Negative Binomial model

The Negative Binomial distribution is an alternative to Poisson model and especially useful for count data whose sample variance exceeds the sample mean i.e., data with over-dispersion.

The probability mass function of a Negative Binomial distribution is

$$P_{NB}(Y_i = y_i|x_i) = \frac{\Gamma(y_i + 1/\alpha)\,(\alpha\mu_i)^{y_i}}{y_i!\,\Gamma(1/\alpha).\,(1+\alpha\mu_i)^{y_i+1/\alpha}} \quad y_i = 0,1,2,\ldots\ldots$$

with Mean

$$E(y_i|x_i) = \mu_i = exp(x_i'\beta)$$

and Variance

$$V(y_i|x_i) = \sigma_i^2 = \mu_i(1+\alpha\mu_i)$$

Zero truncated Poisson model

The probability mass function of a Zero truncated Poisson distribution is

$$P_{tpoi}(Y_i = y_i|x_i) = \frac{e^{-\mu_i}\mu_i^{y_i}}{(1-e^{-\mu_i})y_i!}, \quad y_i = 1,2,\ldots$$

with Mean

$$E(y_i|x_i) = \frac{\mu_i}{1-e^{-\mu_i}}$$

and Variance

$$V(y_i|x_i) = \sigma_i^2 = \frac{\mu_i(1+\mu_i)}{(1-e^{-\mu_i})} - \frac{\mu_i^2}{(1-e^{-\mu_i})^2}$$

Zero truncated Negative Binomial model

The probability mass function of Zero truncated Negative Binomial distribution is obtained by dividing the probability mass function of Negative Binomial distribution by [1- P (0)].

By writing $\omega = \frac{1}{1+\alpha\mu_i}$ and $\eta = 1-\omega,$

The probability mass function of a Zero truncated Negative Binomial distribution can be written as

$$P_{TNB}(Y_i = y_i|x_i) = \frac{\Gamma(y_i + 1/\alpha)}{y_i!\,\Gamma(1/\alpha)}\;\frac{\omega^{1/\alpha}\quad\eta^{y_i}}{1-\omega^{1/\alpha}} \quad y_i = 1,2,\ldots\ldots$$

with Mean $$E(y_i|x_i) = \frac{\mu_i}{1-(1+\alpha\mu_i)^{-(1/\alpha)}}$$

and Variance $$V(y_i|x_i) = \sigma_i^2 = \frac{\mu_i[(1+\alpha\mu_i) - (1-\alpha\mu_i+\mu_i)\,(1+\alpha\mu_i)^{-(1/\alpha)}]}{(1-(1+\alpha\mu_i)^{-(1/\alpha)})^2}$$

Selection of models and their evaluations

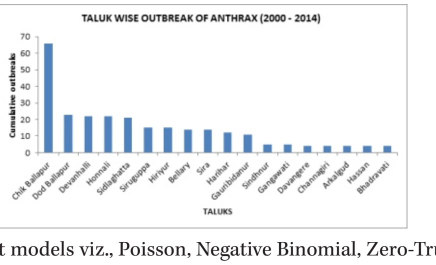
To model outbreak of Anthrax, taluk-wise average of each risk factor was considered as independent variables and outbreaks in these taluks were considered as dependent variable. The interaction effect of various combinations of risk factors was also studied. Initially Zero truncated Poisson regression model was considered for the modelling Anthrax outbreaks, and then a model using Zero truncated negative binomial distribution was considered. Along with truncated models, Poisson and Negative binomial regression models were also considered.

PROC GENMOD procedure of SAS® software was used to fit Poisson and Negative Binomial models. PROC FMM procedure was used to fit Truncated Poisson distribution and PROC NLMIXED procedure was used to fit Truncated Negative Binomial distribution. Goodness of fit of models was evaluated using Pearson's Chi-Square test statistic, Akaike information criterion (AIC), AICC for correction for finite sample size and Baysian Information Criterion (BIC). Goodness of fit was tested using Chi-square goodness of fit with 5% level of significance.

Results

A total of 51 taluks out of 177 taluks in Karnataka have reported outbreak of Anthrax during the period 2000 -2014. Chikkaballapura taluk in Chikkaballapura district recorded maximum number of outbreaks. Figure 1 shows major outbreaks of Anthrax.

Figure 1 Taluk wise outbreaks of Anthrax



The count models viz., Poisson, Negative Binomial, Zero-Truncated Poisson and Zero-Truncated Negative Binomial models were used to fit the data on taluk wise outbreak of Anthrax using Remote sensing variables LST and NDVI, Climatic variables Temperature and Rainfall, Soil type, Soil pH and Soil nutrients such as Organic Carbon, Sulphur, Potassium, Phosphorus, Zinc and Boron.

The Models were evaluated using Fit statistics AIC, AICC and BIC. Lower values of these indices indicate the better fit of the models. Before evaluating the models using these Indices, the models were tested for their fit by computing Pearson's Chi Square statistic and comparing the predicted values of the outbreak of Anthrax with the actual values. The results of models fit with their predicted values ore presented in table 1. The fit statistics are presented in table 2.

Table 1 Predicted values of Anthrax for various models

		Observed outbreaks	Predicted outbreaks					
Taluk	**Livestock population**	**Number**	**Rank**	**Poisson**	**Negative Binomial**	*** Zero truncated Poisson**	**Zero truncated Negative Binomial**	**Residual for the best model (*)**
Chik Ballapur	51799	66	1	65.8389	65.891	65.3773	66.2988	0.6227
Dod Ballapur	14852	23	2	22.1395	22.0443	24.5097	24.0206	-1.5097
Devanhalli	15495	22	3	21.7533	21.6249	19.7906	22.6498	2.2094
Honnali	22971	22	3	16.5722	16.6358	19.6427	19.6603	2.3573
Sidlaghatta	21488	21	5	22.4457	22.7657	22.8597	20.7814	-1.8597
Siruguppa	49149	15	6	10.9743	10.8352	12.1796	12.3402	2.8204
Hiriyur	62777	15	6	15.4269	15.5456	14.9143	15.3876	0.0857
Bellary	122988	14	8	16.6036	16.6107	15.6786	15.2822	-1.6786
Sira	33865	14	8	14.2408	13.8975	12.5933	13.073	1.4067
Harihar	26341	12	10	9.8495	10.0604	14.9951	11.1323	-2.9951
Gauribidanur	9940	11	11	9.1274	9.0936	10.9993	8.4479	0.0007
Sindhnur	10087	5	12	3.1051	3.1733	4.993	5.5732	0.007
Gangawati	7933	5	12	5.3801	5.3257	5.0842	5.6728	-0.0842
Davangere	3101	4	14	3.4933	3.482	2.6861	2.513	1.3139
Channagiri	5639	4	14	4.1064	4.1771	3.7046	3.987	0.2954
Arkalgud	1921	4	14	2.2062	2.21	3.26	3.2249	0.74
Hassan	9804	4	14	2.1494	2.1478	2.5376	3.3369	1.4624
Bhadravati	2801	4	14	4.1584	4.1447	4.1443	3.952	-0.1443
Hospet	30371	3	19	4.1592	4.1093	3.1211	4.2168	-0.1211
Chamrajnagar	2587	3	19	2.7543	2.7754	2.0985	1.1942	0.9015
Shiggaon	2469	3	19	2.2415	2.2168	1.9082	0.3741	1.0918
Sandur	10808	3	19	4.1105	3.945	1.2054	3.1558	1.7946
Mulbagal	4103	3	19	7.1726	7.1056	3.6841	5.2584	-0.6841
Bangalore N	1401	3	19	1.9789	2.0052	1.5446	0.762	1.4554
Deodrug	5938	2	25	1.1033	1.1031	1.919	0.7353	0.081
Manvi	10142	2	25	2.6033	2.6266	1.2162	1.1187	0.7838
Arsikere	1220	2	25	1.8606	1.8399	1.9019	1.1309	0.0981
Chitradurga	2056	2	25	1.0825	1.1012	1.6379	0.4547	0.3621
Srinivaspur	1006	2	25	2.0254	2.0036	2.4314	1.6739	-0.4314
Chintamani	1192	2	25	4.8955	4.9241	3.7637	3.643	-1.7637
Kollegal	2510	1	31	0.6019	0.6091	1.0243	0.722	-0.0243
Aurad	841	1	31	2.6232	2.6886	1.2209	1.8309	-0.2209
Somvarpet	2260	1	31	2.0811	2.0946	1.0272	0.309	-0.0272
Haveri	3793	1	31	1.0748	1.0614	1.0254	0.2576	-0.0254
Sorab	635	1	31	3.1529	3.1401	1.8949	3.2403	-0.8949
Chiknayakanhalli	159	1	31	0.451	0.4128	1.0009	1.0373	-0.0009
Tiptur	1025	1	31	1.7905	1.8123	1.6571	0.1709	-0.6571
Shorapur	3800	1	31	0.6714	0.681	1.2849	0	-0.2849
Navalgund	2955	1	31	0.9164	0.9128	1	0.0003	0
Hunsur	568	1	31	2.5895	2.6562	1.1833	0.1619	-0.1833
Madhugiri	811	1	31	1.1544	1.1725	1.4837	1.3337	-0.4837
Shikarpur	1554	1	31	0.5135	0.5191	1.0064	0.0055	-0.0064
Shimoga	1080	1	31	1.493	1.5385	1.6502	0.3896	-0.6502
Gundlupet	1282	1	31	0.0909	0.0934	1	0.0027	0
Ranibennur	1435	1	31	1.7843	1.8369	1.4374	0.7209	-0.4374
Raichur	2585	1	31	3.0363	2.9752	2.9975	1.4925	-1.9975
Bangalore S	360	1	31	1	1	2.0837	0.0001	-1.0837
Byatha	420	1	31	0.616	0.6259	1.2088	0.3042	-0.2088
Malur	1365	1	31	2.0149	2.0228	1.4115	0.6054	-0.4115
Tirthalli	635	1	31	1.4753	1.4614	1.8445	0	-0.8445
Turuvekere	2877	1	31	1.3105	1.2641	1.1755	0.2626	-0.1755

Fig 1 showing Actual and Predicted values of Anthrax for various models

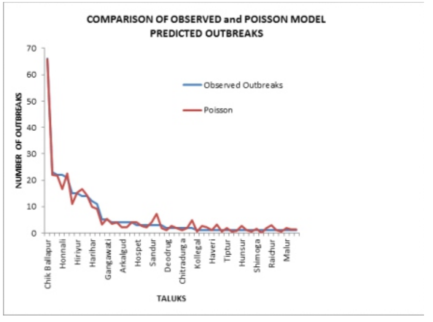


Fig 2

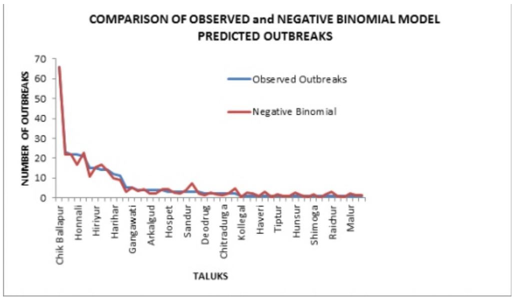


Fig 3

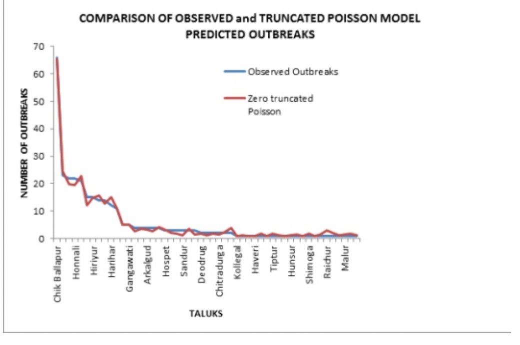


Fig 4

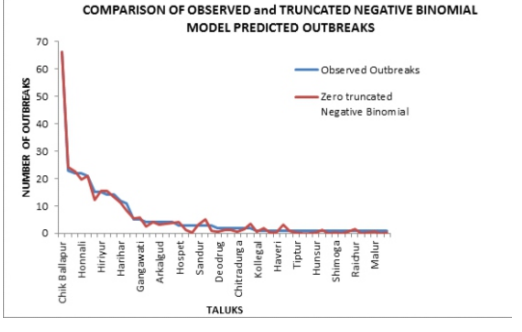


Table 2 Fit statistics

	POISSON	NEGATIVE BINOMIAL	ZERO TRUNCATED NEGATIVE BINOMIAL	ZERO TRUNCATED POISSON
AIC	226.7713	230.7224	217.5	177.4
AICC	267.6602	282.7224	545.5	205.4
BIC	271.2033	279.0181	294.8	216

Table 1 and Fig 1 to 4 shows that the actual and observed outbreaks are almost matching for Zero truncated Poisson distribution. Further this was supported by the Fit statistics AIC, AICC and BIC in Table 2, as it may be noted that the Fit statistics are the least for Zero truncated Poisson distribution.

The following observations are made by utilising the Parameter estimates of Zero Truncated Poisson model.

- The interaction of one month lag of NDVI with soil nutrient Organic Carbon is highly associated high risk of outbreak of Anthrax.
- The interaction of lag period of NDVI with soil pH also plays significant role in the outbreak of Anthrax.
- LST and its one month lag have also contributed, though not as much as NDVI to the outbreak of Anthrax.
- The deficient amount of Boron adds as catalyst to the outbreak of Anthrax.

Finally, using ArcGIS® software, a Risk map forecasting the outbreak of Anthrax at taluk level was developed using Zero truncated Poisson regression model. Risk map model shows that Chikkaballapura taluk has the maximum risk of outbreak of Anthrax, followed by Devanahalli, Doddaballapura, Sidlaghatta Hiriyur, Honnali and Bellary. The taluks with very low risk of outbreak were Arasikere, Aurad, Bhadravati, Chitradurga, Chamarajnagara, Gundlupet, Haveri, Hunsur, Kollegala, Manvi, Navalgund, Ranibennur, Shorapur, Sandur, Shiggaon and Tiptur.

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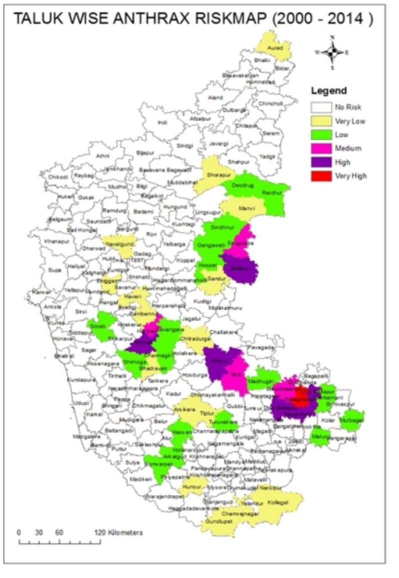
Fig 5: Taluk-wise Risk map of anthrax in Karnataka



Discussion

Descriptive epidemiological studies of Anthrax provide valuable insights into the effects of outbreaks on population, duration and location of the outbreaks and percent mortality. (Kellogg et al., 1970). The grazing pattern and seasons will also play an important role in outbreak precipitation. (Salb et al., 2014). A series of surveys showed an annual increase in the seasonal trends in the incidence of anthrax in India which has been during rainy season and also during winter season. Outbreaks occur during the dry months that followed a prolonged period of rain when the spores are exposed and the ruminants have greater access to them. The awareness of this fact amongst the farming community and the disease preventive and control measures taken up by the authorities might have resulted in reduced number of outbreaks. Though there is a decreasing trend in the occurrence of anthrax, it is still hyper endemic or hyper enzootic in many pockets of the country. This can be attributed to improper disposal of the carcasses of those animals died due to Anthrax and lack of public awareness. Many cases of anthrax go unreported since it occurs as an isolated incidence and under reporting of the cases by the field staff. Hence, the mere absence of reported outbreaks is no proof of absence of the disease. Thus, the reported outbreaks only provide an index of the magnitude of the disease in India and could be an under rate of the problem.

Anthrax assumes highly significant place both in animal health and agricultural economy since it is peracute in nature and the farmer suffers a heavy financial loss due to loss of valuable animals. It is also important since it is a zoonotic disease and has a potential to be used as a weapon for bioterrorism. Due to its importance, the government undertakes annual vaccination of the livestock and building up of awareness amongst the farming community about its human transmissibility. This also reflects on the effectiveness of the control measures carried out by annual vaccination.

Count regression models are used when the dependent variables takes on non-negative integer values. These values represent the number of times an event occurs in a fixed domain (Cameron and Trivedi, 1996 and Long, 1997). There are varieties of models that deal with count dependent variables. The benchmark Poisson model imposes the distribution restriction that conditional variance equals the conditional mean that is equidistribution. This stringent restriction is usually rejected in various applications and other modelling distributions must be considered. Mixed-Poisson distributions have been found useful in conditions where counts display over dispersion that conditional variance exceeds the conditional mean. In case of over dispersion, the Negative Binomial model is usually preferred. For under dispersion with conditional variance is less than conditional mean, there are fewer model options. Since there is no model that covers only the underdispersion, with undispersed data, it is necessary to consider models that have variance function flexible enough to cover both over and under dispersion.

In the present study Zero-Truncated Poisson distribution emerged as best fit model for Anthrax outbreak in Karnataka as depicted in Table 1 and the figures indicate that the actual and observed outbreaks are almost matching for Zero truncated Poisson distribution. Further this was supported by the Fit statistics AIC, AICC and BIC as shown in Table 2, as Fit statistics are the least for Zero truncated Poisson distribution.

Conclusion

The aim of the study was to determine the type of model which fitted the retrospective data on outbreak of Anthrax and to develop a Risk map which forecasted the outbreak of the disease at taluk level.

The findings of the study suggest that Zero Truncated Poisson model provided the best fit for the taluk wise outbreak of the disease. The model can be improved by taking other factors like relative humidity, other remote sensing variables like NDWI and NDMI, Further research with richer data like vaccination status and disease control measures might enhance the Anthrax model predictabilities.

Other factors such as sociological, health conditions of livestock, lack of knowledge about the risk of Anthrax among farming community, preventive and control measures taken by the concerned authorities may also play important roles in the endemicity of the disease.

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