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Forecasting Anthrax in Livestock in Karnataka State using Remote Sensing and Climatic Variables

Suma A P[1], Suresh K P[2], Gajendragad M R[3], Kavya B A[4]

[1]Research Scholar, Jain University, Bengaluru, India

[2]Senior Scientist, National Institute of Veterinary Epidemiology and Disease Informatics

[3] Emeritus Scientist, National Institute of Veterinary Epidemiology and Disease Informatics

[4] Senior Research Fellow, National Institute of Veterinary Epidemiology and Disease Informatics

Abstract: ***Anthrax is a well-known zoonotic disease caused by Bacillus anthracis, a gram positive, spore forming bacteria. In livestock it is usually peracute and fatal whereas in humans it is a highly fatal disease, 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 modeling 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, past anthrax outbreak data was analyzed anda forecasting model is developed. To develop the model, in the risk factor domain, amount of rainfall, atmospheric temperature, 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 tools (MODIS Tools). Zero Truncated Poisson regression with log link model was used for developing the climate-anthrax relationship model with outbreak of anthrax as dependent variable and LST, NDVI, amount of rainfall and soil nutrients were considered as predictors in the model. Then a risk map forecasting the outbreak of anthrax was generated.***

Keywords: Anthrax, Remote-sensing, Zero-truncated Poisson, Risk-map

1. Introduction

Anthrax is an ancient disease caused by *Bacillus anthracis*, a gram positive, spore-forming, rod-shaped bacterium. The organism is readily cultivable on routine nutrient medium and grows best aerobically, but will also multiply under anaerobic conditions [24].The disease in livestock is usually peracute, characterized by septicemia and sudden death in 1-3 hours with exudation of unclotted tarry coloured blood from natural orifices, incomplete rigor mortis and splenomegaly in cattle [22].It is a potential zoonotic disease, readily transmitted to human beings via inhalation of spores, handling of infected animals, consumption of contaminated meat, contaminated carcass, contaminated fomites etc. *Bacillus anthracis* possess three plasmid-encoded virulence factors: a poly-γ-D-glutamic acid capsule that inhibits phagocytosis; edema toxin composed of protective antigen (PA) and edema factor (EF); and lethal toxin a combination of PA and lethal factor (LF). Both toxins bind to a common cell receptor through PA. Production of anthrax toxin within an animal is dependent on the presence of viable *B. anthracis*, hence the detection of PA is indicative of active anthrax infection [2].

2. Literature Survey

Anthrax is widely prevalent in many parts of Eastern Europe, southern Europe, Africa, South America, central Asia and south East Asia including India. Though it is prevalent throughout India, its 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 [16], [26].

Modeling of anthrax can help in understanding the dynamics and epidemiology of the disease by identifying and quantifying likely contributing factorssuch as rainfall, temperature, soil profile etc. The model can also be used to evaluate the effectiveness of control measures taken to prevent or spread the disease. Retrospective anthrax disease data from Karnataka state of India has been used. Karnataka is located approximately between 11.5°N and 18.5° N latitudes, 74°Eand 78.5°E longitude. The annual average annual rainfall here is around 1335 mm. The Coastal region receives the highest rainfall, while the North interior Karnataka receives the least rainfall. The annual average temperature ranges from 20° Cto 34° C. Modeling of anthrax can help in reducing the economic loss due to anthrax by forewarning the livestock farmers to take up necessary preventive measures and also loss due to mortality.

3. 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, village based on the month and year of occurrence of anthrax outbreaks.

Statistical analysis

Perusal of literature on anthrax shows that factors like temperature, rainfall, vegetation, soil type and water resources play a major role in the outbreak of the disease. To supplement these risk factors, 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 recorded. 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. Zero Truncated Poisson regression with log link model was used for the analysis. The analysis was done using statistical SAS® software. Risk map forecasting the outbreak of the disease was prepared using ArcGIS® software.

Remote sensing

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 to the surface on the earth. After the interaction of radiation with the earth's surface, it is transmitted back to the remote sensor mounted on a satellite. The sensor data is then transmitted to a ground station, where it is processed and analyzed. This processed data is used for variety of applications.

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 HDF file obtained was imported into Erdas Imagine software and was processed to get the pixel value.

Land Surface Temperature (LST) is the measure of how hot the surface of the earth would feel to the touch in a particular location. Land surface temperature measure is not the same as the air temperature measure.

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

4. Results

District wise outbreak of anthrax

Out of the 30 Districts in Karnataka, 19 have reported anthrax during the period 2000 to 2014. Chikkaballapura district has the highest number of outbreaks, followed by Bangalore Rural district. Bidar, Dharwad, Gulbarga, Kodagu and Mysore recorded the least number of outbreaks. Figure 1 shows district wise outbreak of anthrax.

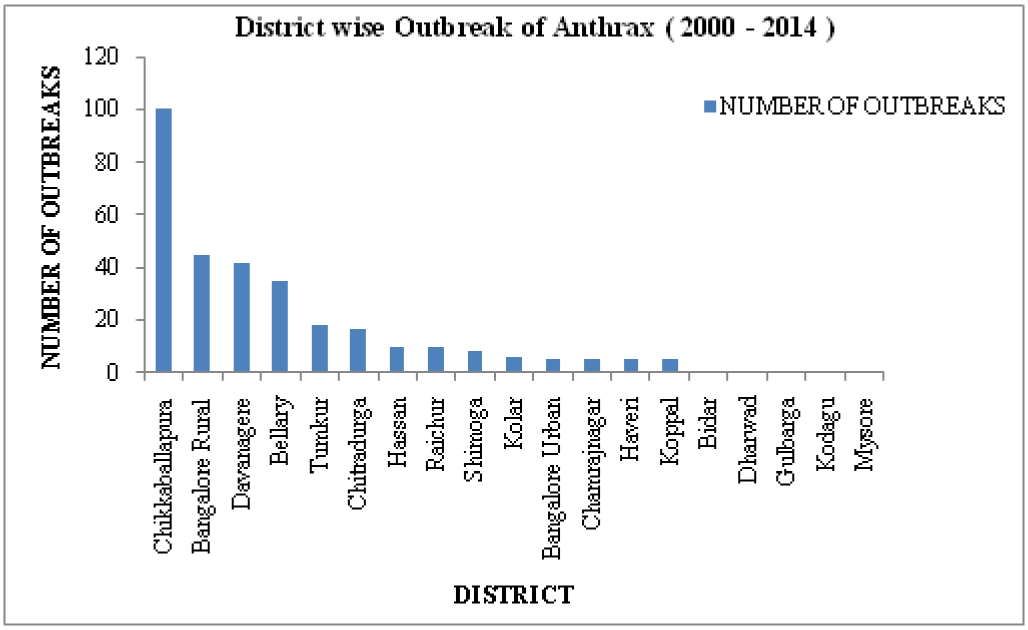


Figure 1: District wise outbreak of anthrax

Year wise outbreak of anthrax

Maximum number of outbreaks occurred in the year 2001. From the year 2001 to the year 2006, there was almost consistent number of outbreaks, but then the outbreaks decreased considerably till the year 2008. Again there was little raise in the number of outbreaks in the year 2009 and then it started decreasing till the year 2012 and then again started increasing. Figure 2 shows year wise outbreak of anthrax.

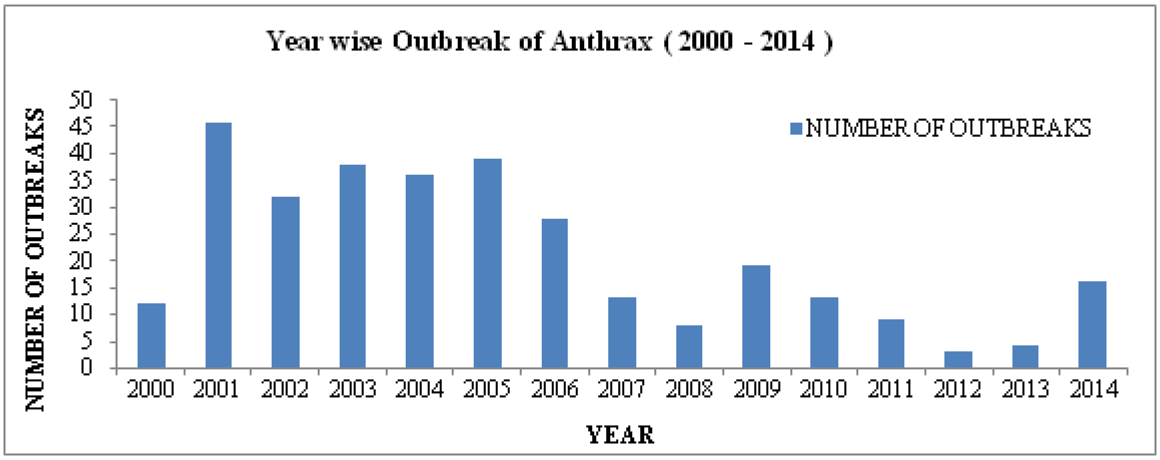


Figure 2: Year wise outbreak of anthrax

Monthwise outbreak of Anthrax

It may be noted that the monsoon months of August, September and October recorded the maximum outbreaks, peak being in the month of October. Figure 3 shows month wise outbreak of anthrax.

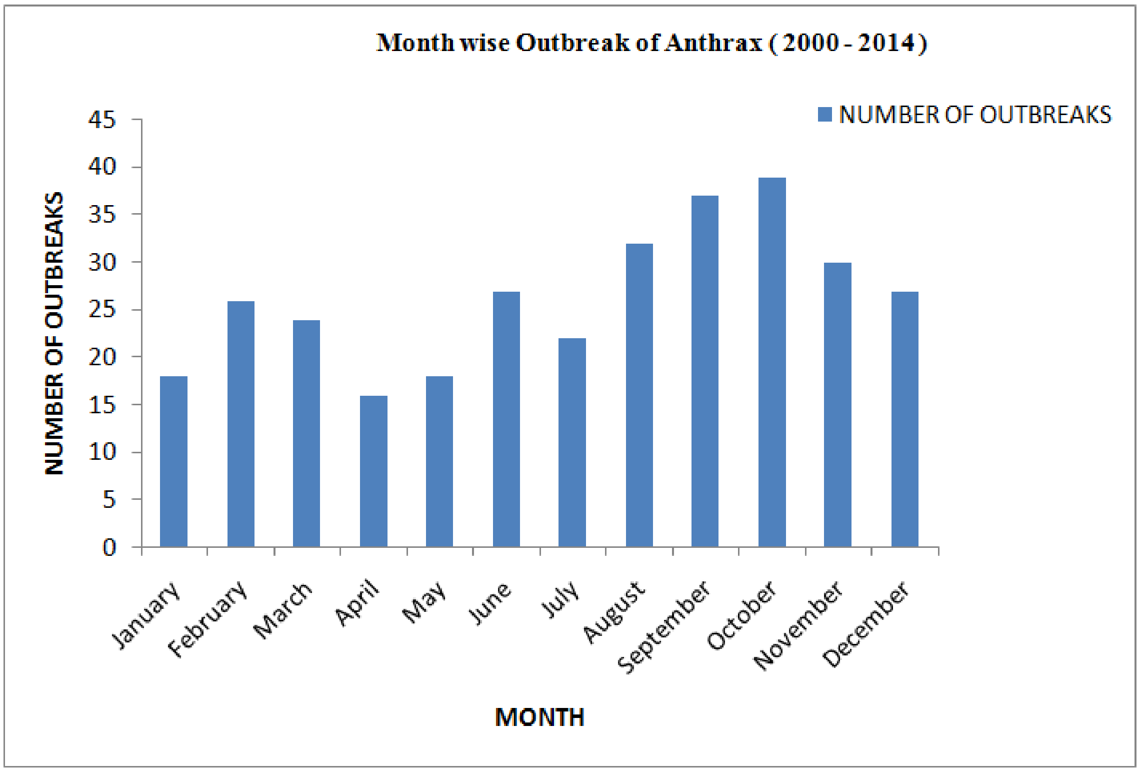


Figure 3: Month wise outbreak of anthrax

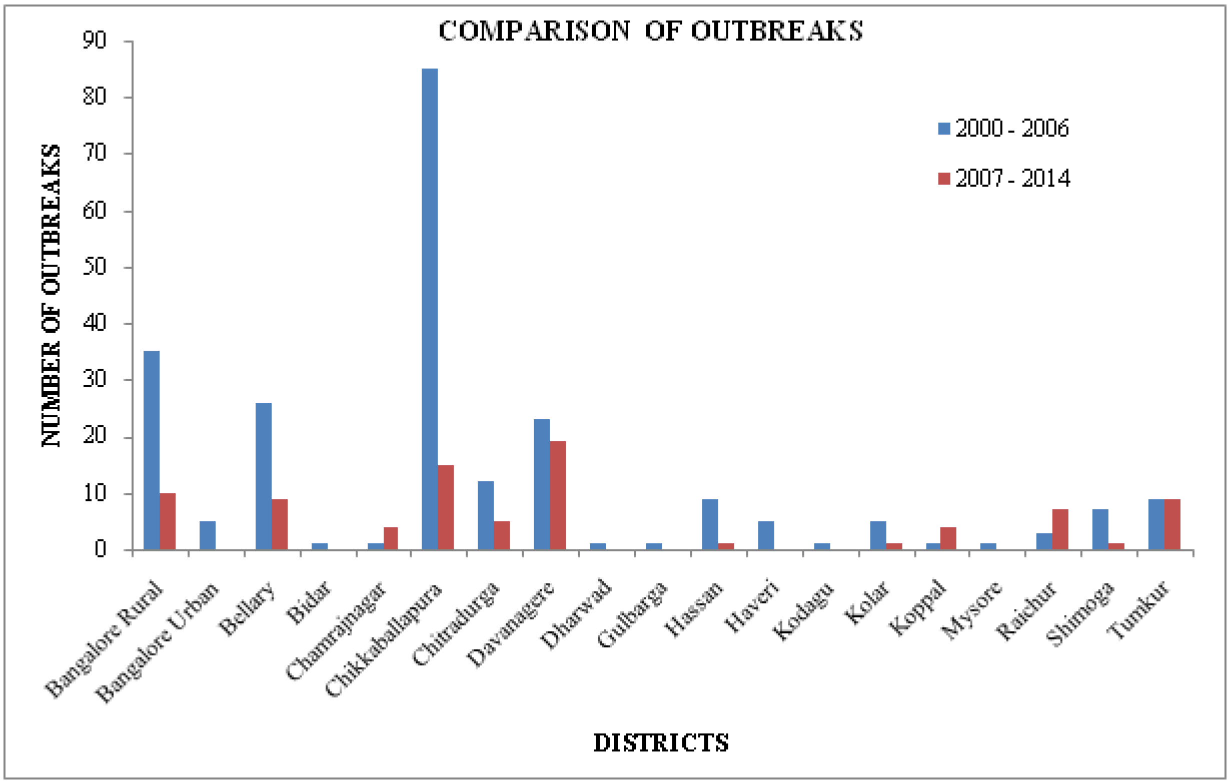
Comparison of outbreaks

Year wise analysis of the outbreaks indicates that there is consistency in the pattern of outbreaks between the periods 2000 – 2006 and 2007 – 2014. Detailed observation indicates:

- The outbreaks reduced in most of the districts.
- Some districts like Bangalore Urban, Bidar, Dharwad, Gulbarga, Haveri, Kodagu and Mysore did not report outbreak at all during the period 2007 – 2014.
- Chamrajnagar, Koppal and Raichur districts reported slightly higher number of outbreaks during 2007 -2014 as compared to 2000 -2006.
- Tumkur district reported same number of anthrax outbreaks between the two periods.

Figure 4 shows the comparison of anthrax outbreaks between the two periods.

Figure 4Comparison of outbreaks of anthrax



Cumulative outbreak of Anthrax

District wise cumulative outbreak of Anthrax during the period 2000 – 2014 was depicted using ArcGIS® software.

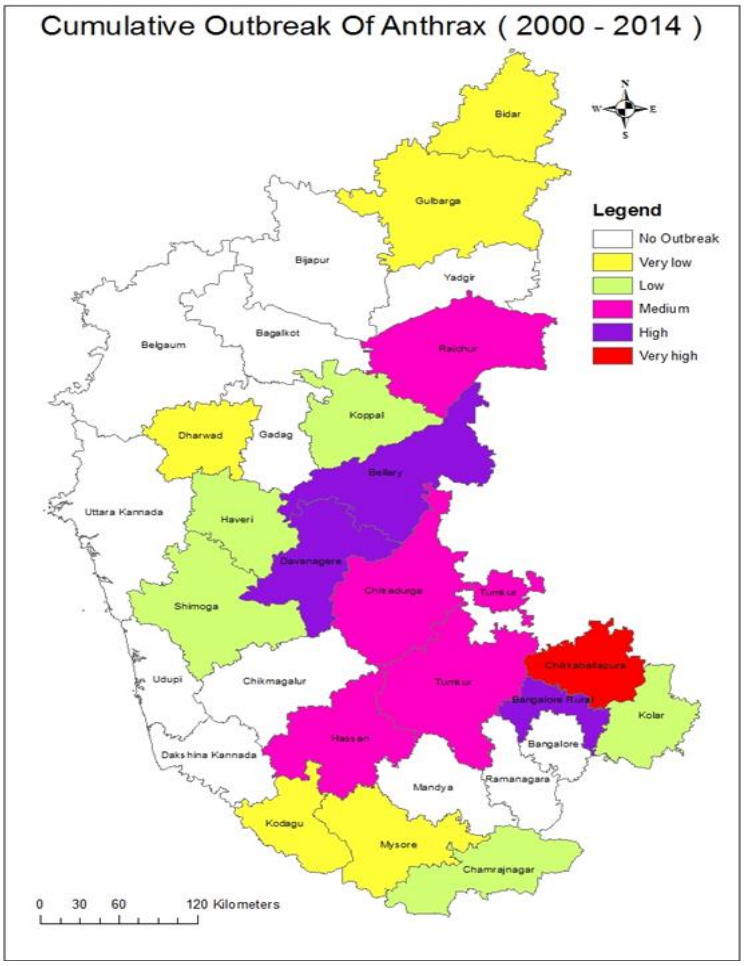


Figure 5: Cumulative outbreak of anthrax

The analysis

Data considered for the analysis

The predictive power of the variables LST, NDVI, soil nutrients, temperature and amount of rainfall was assessed for their contribution to the outbreak of anthrax. One month lag period was also measured for LST and NDVI and was included in the analysis. Then the district wise average of the variables was considered for developing a statistical model with these predictors and historical district wise anthrax outbreaks as response variable, which would describe possible relationship between these factors and whether these relationships can tell us anything about future anthrax outbreak.

Generalised Linear Models

In Linear models, we assume that the distribution of the response variable (Y_i) is Normal with mean μ_i and common variance σ^2. The function of the explanatory variablesis $\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots\ldots\ldots + \beta_k x_k$. We assume that the connection between explanatory variables and the distribution of the response variable as

$\mu_i = E(Y_i) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots\ldots\ldots + \beta_k x_k$

Generalised Linear model is an extension of traditional or classical linear model. In Generalised Linear Models, the distribution of response variable is any member of Exponential family. The connection between the explanatory variables and the distribution of the response variable is established through a nonlinear link function.

Zero Truncated Poisson regression with link function as log

If the response variable is in the form of counts and cannot take the value zero, Zero truncated Poisson distribution is the most appropriate distribution for modeling. Here the logarithm of mean of the response variable is linked to a linear function of explanatory variables.

The Zero Truncated Poisson distribution

A random variable Y with the following probability mass function is said to follow Zero Truncated Poisson distribution.

$P(Y = y) = \frac{e^{-\mu}\mu^y}{(1-e^{-\mu})y!}$ $\quad$ Y = 1, 2 ……. and $\mu > 0$.

A Truncated Poisson regression model with a log link function is given by

$\text{Log}(\mu) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots\ldots\ldots + \beta_k x_k$

with the estimation

$\mu = \text{Exp}(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots\ldots\ldots + \beta_k x_k)$

The data was analyzed using SAS® software. The data was modeled with procedure FMM with Truncated Poisson distribution and Log link function. It can be seen from the parameter estimation table that the remote sensing variables LST and NDVI with their one month lag period data contribute significantly to the outbreak. Of the six soil nutrients considered, Potassium and Phosphorus did not contribute to the outbreak whereas, Sulphur, Organic carbon, Boron and Zinc contributed significantly to the outbreak of the disease. Temperature data did not play major role in the outbreak of the disease. The analysis of parameter estimates is given in Table1.

Table 1: Parameter Estimates for 'Truncated Poisson' Model

Parameter Estimates for 'Truncated Poisson' Model				
Effect	Estimate	Standard Error	z Value	Pr> |z|
Intercept	-1.6738	2.9154	-0.57	0.5659
LST	-0.1163	0.08594	-1.35	0.1758
LST lag	0.3386	0.06545	5.17	<.0001
NDVI	-29.9836	3.1793	-9.43	<.0001
NDVI lag	21.8911	2.9157	7.51	<.0001
Sulphur	2.7877	0.2916	9.56	<.0001
Zinc	-1.959	0.3468	-5.65	<.0001
Organic Carbon	1.0439	0.3017	3.46	0.0005
Boron	-3.719	0.3356	-11.08	<.0001
Rainfall	0.04885	0.006632	7.37	<.0001
Excessive Rainfall	-2.9669	0.2812	-10.55	<.0001

The data on these variables was converted to raster dataset using ArcGIS® software and a Risk map forecasting the outbreak of anthrax was developed. The Risk map matched with the cumulative outbreak map, proving that Truncated Poisson distribution is the best fit to the observed data. Risk map model shows that Chikkaballapura district has the maximum risk of outbreak of anthrax, followed by Bangalore Rural, Davanagere and Bellary districts. Bidar, Gulbarga, Dharwad, Koppal, Kodagu and Mysore districts have the least risk of outbreak. Figure 6 shows the Risk map of anthrax.

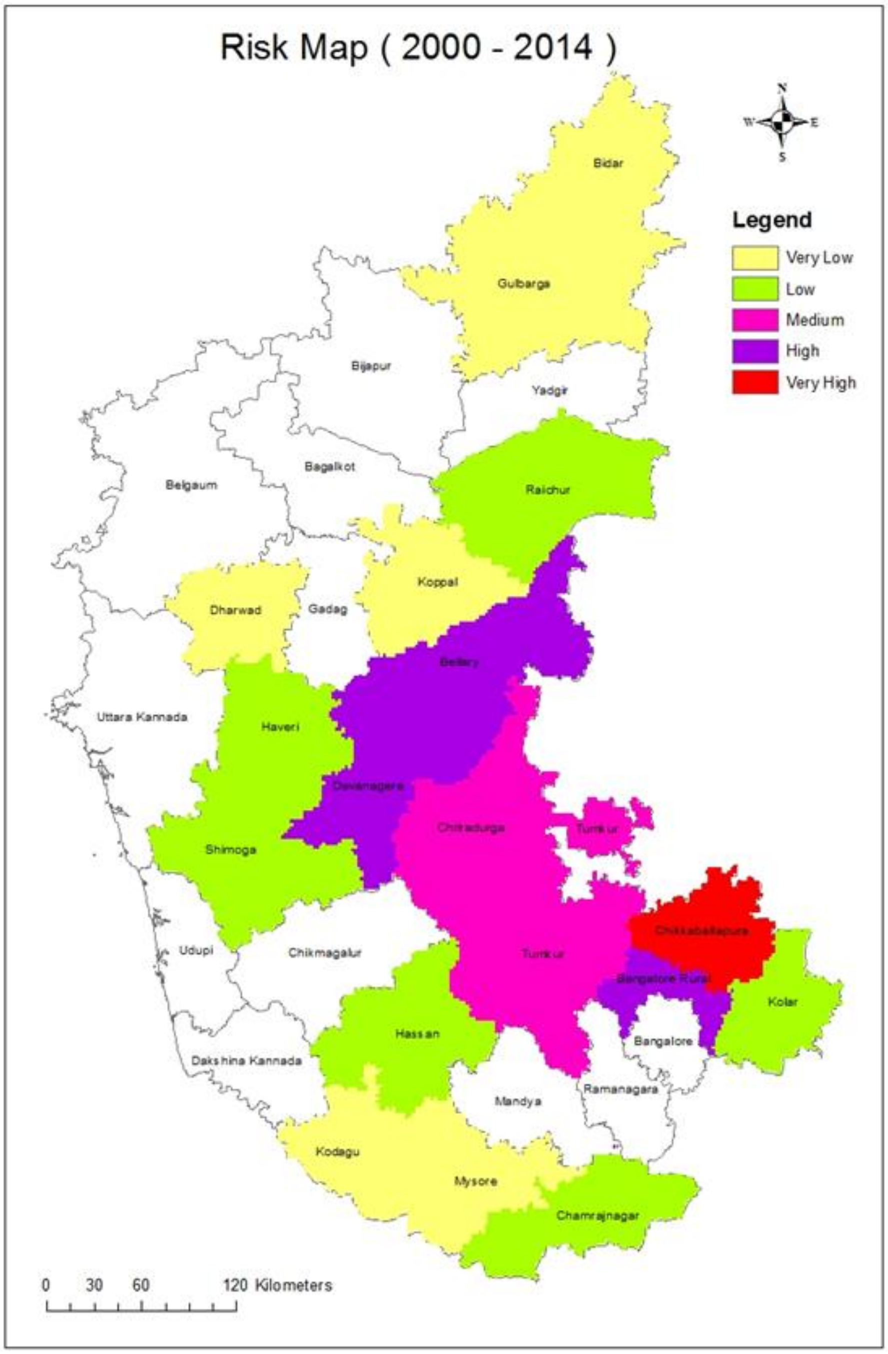


Figure 6: Risk map of anthrax

5. Discussions

The outbreak of anthrax gradually decreased from the time period 2000 – 2006 to the time period 2007 – 2014. This may be because of the preventive and the control measures taken by the concerned authorities. The awareness among the farming community about the risk of anthrax might be another reason for the reduction in the number of outbreaks. Though the occurrence of anthrax is reducing, it is still enzootic in many places. Sociological and health conditions of livestock may be the reasons for this endemicity.

In this paper, only two remote sensing variables were considered for forecasting anthrax outbreak. The study can be improvised by taking other remote sensing variables like Normalized difference moisture index (NDMI) and Normalized difference water index (NDWI). Also, since livestock is transported from one place to another and that it is an infectious disease, distance factors like distance of the place where the outbreak has occurred to the nearby city, road, highway, railway track and water body can also be considered for the study.

6. 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.

The findings of the study suggest that Zero Truncated Poisson model provided the best fit for the district wise outbreak of the disease. Model was fitted using few variables. 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. So, preventive and control measures must be very effectively implemented in these areas. Also, educating livestock farmers regarding anthrax is essential to eradicate anthrax.

7. Future Scope

The model can be improved by taking other factors like relative humidity, NDWI, NDMI, soil pH and soil types. Further research with richer data, including vaccination status, disease control measures might further improve the anthrax model predictabilities.

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