SPATIAL MAPPING OF FOOT AND MOUTH DISEASE IN KARNATAKA USING GIS, REMOTE SENSING, AND NOVEL STATISTICAL MODELS

A THESIS TO BE SUBMITTED TO

THE UNIVERSITY OF TRANS-DISCIPLINARY HEALTH SCIENCES AND TECHNOLOGY

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FOR THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY

BY

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UNDER THE GUIDANCE OF

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THE UNIVERSITY OF TRANS-DISCIPLINARY HEALTH SCIENCES AND TECHNOLOGY

Private University Established in Karnataka by ACT 35 of 2013

BENGALURU - 560064

DECLARATION BY THE CANDIDATE

I declare that this thesis entitled "**Spatial Mapping of Foot and Mouth Disease in Karnataka Using GIS, Remote Sensing, and Novel Statistical Models**" submitted for the award of Doctor of Philosophy to THE UNIVERSITY OF TRANS-DISCIPLINARY HEALTH SCIENCES AND TECHNOLOGY, Bengaluru, is my original work, conducted under the supervision of my guide, Dr. Mohammed Mudassar Chanda. I also wish to inform that no part of the research has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged.

I hereby confirm the originality of the work and that there is no plagiarism in any part of the dissertation.

Place: Bengaluru **Signature of the Candidate**

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CERTIFICATE

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Affectionately Dedicated

to My parents, Mother In-law

Lovely Husband,

Hamsini, and Pankaj

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List of Acronyms

AIC	Akaike information criterion
AICC	Akaike information criterion for correction
AICRP	All India Co-Ordinated Research Project
BHK	Baby Hamster Kidney
BIC	Bayesian information criterion
BIE	Trivalent Binary Ethyleneimine
BRT	Boosted Regression tree
DADF	Department of Animal Husbandry Dairying & Fisheries
DAH&VS	Department of Animal Husbandry & Veterinary Services
dLST	Daytime land surface temperature
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organisation
FMD	Foot and Mouth Disease
FMDCP	Foot, and Mouth Disease Control Project
FMDV	Foot and Mouth Disease Virus
GARP	Genetic Algorithm for Rule-set Production
GDP	Gross Domestic Production
GIS	Geographic information system
GLEWS	Global Early Warning System
GOI	Government of India
ICAR	Indian Council of Agriculture Research
IAH&VB	Institute of Animal Health and Veterinary Biologicals
Km	Kilometer
mm	Millimeter
MODIS	Moderate Resolution Imaging Spectroradiometer
MSE	Mean Squared error
NDVI	Normalized Difference Vegetation Index
nLST	night-time land surface temperature
OIE	Office International des Epizooties
PCP	Progressive control pathway
PD-FMD	Project Directorate on Foot and Mouth Disease

QGIS	Quantum geographic information system
ROC	Receiver Operative curve
RMSE	Root Mean Square Error
RS	Remote Sensing
SAT	South African territory
SPSS	Statistical Package for Social Sciences
TCID	The tissue culture infective dose
TDU	The University of Trans-Disciplinary Health Sciences and Technology
WHO	World Health Organization
WOAH	World Organization for Animal Health

Spatial Mapping of Foot and Mouth Disease in Karnataka Using GIS, Remote Sensing, and Novel Statistical Models

Abstract

Foot and Mouth disease (FMD) is a highly contagious viral disease of domestic and wild cloven-hoofed animals, including cattle, buffalo, sheep, goats, pigs, water buffalo, and wild species (OIE, 2012). The disease was caused by Foot and Mouth Virus (FMDV) belonging to the family *Picornaviridae* and genus *Aphthovirus* (Belsham, 1993). The virus has seven serotypes. The existing serotypes are O, A, Asia-1, South Africa territory-1(SAT-1), SAT-2, SAT-3, and C (Domingo *et al.,* 2003). The main clinical symptoms of FMD are high fever (104-105^0 F), salivation, and a significant drop in milk production. The other clinical signs observed due to FMD are painful blisters/ vesicles on the tongue, lips and other tissues of the mouth, udder, teats, and interdigital space of feet (Alexandersen *et al.,* 2003). There is also weight loss, loss of appetite, quivering lips and frothing of mouth, cows may develop blisters on teats and lameness in several animals. Occasionally, FMD can also infect humans (Bauer, 1997). The disease can cause significant socioeconomic losses (Thompson *et al.,* 2002). The direct economic losses due to FMD in India were estimated to be Rs. 200 Billion (Venkataramanan *et al.,* 2005). The projected annual direct loss from FMD in India is Rs. 20,000 crores (Pattnaik et al., 2012b). The mean total loss per animal varied between local and upgraded buffaloes, averaging 440 $ and 513 $, respectively (Govindaraj *et al.,* 2017). Prevention and control of FMD is highly important in protecting the livestock industry and improving the livelihoods of animal-rearing farmers in developing countries where FMD is highly endemic. Currently, there is control program for FMD in India. The success of the disease control program depends on understanding the epidemiology of the disease, especially the spatial analysis of the disease pattern and spread (Bhattacharya *et al.,* 2005). In this thesis it was aimed to identify spatial risk factors, household level risk factors in occurrence of FMD in Karnataka, Further, it was aimed to develop risk map for the disease for planning effective prevention and control strategies. Finally, to make serotype distribution map for the Karnataka state. There are five chapters in this thesis.

Chapter 1. Is the introduction chapter of the thesis covering the importance of animal husbandry sector and contribution to GDP. It deals with the introduction, history of the disease, serotypes of the virus, clinical signs of the disease, disease cycle, transmission of the disease, epidemiology of the disease, vaccination development, prevention and control strategies of the disease and main objectives of the study are mentioned. **Chapter 2.** ***Identified the district level risk factors for the occurrence of Foot and Mouth Disease in Karnataka state***. In this chapter district level outbreaks of FMD for the period between 1977 and 2014 was analysed using livestock census data remote sensed variables at 1 Km spatial resolution using. Poisson and negative binomial regression models. The Negative binomial regression model was the better model (AIC=411.27) compared to Poisson regression model (AIC=4656.72). In the negative binomial regression model, buffalo density and biannual phase of NDVI were positively associated with occurrence of FMD outbreaks. **Chapter 3**. ***Development of high-resolution village level spatial risk map for FMD in Karnataka*. Village** level occurrence of FMD outbreaks from May 2020 to December 2021 and remote sensed variables (MODIS) along with density of cattle and buffalo populations was used to develop risk map for the disease by using machine learning algorithm. The buffalo population, cattle population, and land surface temperature were identified as important risk factors for spatial risk of FMD in Karnataka. The risk map developed showed high risk of the disease in southern region of Karnataka. It shows that the risk of disease increases with an increase in the cattle population. shows that the FMD increases with increase in Minimum and Maximum night-time Land Surface Temperature (LST) until certain point and thereafter it decreases. It means that a certain range of temperature that is influencing the occurrence of the disease in Karnataka. Spatial risk maps for FMD serve as valuable tool for policymakers, veterinary authorities, and other stakeholders to focus on surveillance plan effective prevention and control strategy in high-risk areas. **Chapter 4**. ***Identification of Managemental Risk Factors for Occurrence of FMD in Karnataka Using Statistical Methods*.** The study was aimed to identify household level management risk factors for occurrence of FMD using semi-structured questionnaire. Household level data was collected through personal interviews from 432 households from four villages affected with the disease using binomial regression model. . . It was found that the presence of middlemen in buying and selling of animals (P<0.01), animals that are closely tied together (P<0.01), source of water for livestock (P<0.01), history of FMD (P<0.01), and source of water (P< 0.01) were significant risk factors for the occurrence of FMD in the villages surveyed. Middlemen involved in selling and buying animals should be restricted to move between affected and unaffected villages/households. Animals affected with FMD should be segregated immediately and treated. Clean water should be provided to animals, and mixing of animals at a common source of water can be avoided to prevent the spread of FMD in villages. **Chapter 5**. ***Spatial Mapping of FMD Serotypes in Karnataka***. In India, serotypes O, A, C and Asia 1 are reported. The spatial distribution of different serotypes is not known in Karnataka. In this study, Geographical Information System (GIS) for mapping of different serotypes in different years for Karnataka state. It was found that serotype O is the main serotype in Karnataka. The serotype distribution maps will be useful for planning FMD surveillance and disease control strategies for the state of Karnataka and can be extended to other states of India. Overall, the study identified risk factors for the diseases, developed risk map and prepared serotype distribution maps for the state of Karnataka using remote sensing, GIS and appropriate statistical methods. The study is important considering the burden of the disease even after vaccination. The outcome of the study will be helpful for policy makers to plan effective surveillance, systematic vaccination.

Key Words: *Serotype, Stepwise Regression analysis, Binomial logistic regression, Poisson Regression, Negative Binomial Regression and Akaike Information Criteria, FMD, risk map, vaccination, surveillance, Risk factor.*

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1. Chapter 2 findings were presented as a poster at the **INTERNATIONAL JOURNAL OF INFECTIOUS DISEASES (IMED-2022)** Conference.
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List of Publications

1. **Veena R,** Hegde R, Chetan HC, Megeri SN, Chanda MM. 2024. Spatial mapping of foot and mouth disease serotypes in Karnataka using geographical information system (GIS). *Res. Jr. Agril. Sci*. 15(2): 357-361.

2. **Veena R.,** Raveendra Hegde., Umesh L, Manjunath S Palegar , Chetan H.C., S. N. Megeri., B. R. Shome and Mohammed Mudassar Chanda. Identification of factors responsible for spatial variation of Foot and mouth disease outbreaks in Karnataka using statistical models- To be submitted in peer review journal.

3. **Veena R.,** Raveendra Hegde., Umesh L, Manjunath S Palegar , Chetan H.C., S. N. Megeri., B. R. Shome and Mohammed Mudassar Chanda. Identification of Managemental Risk Factors for Occurrence of FMD in Karnataka Using Statistical Methods– To be submitted in peer review journal.

Chapter 1

General Introduction

1.1 Introduction

1.1.1 Overview of Indian Agriculture, Animal Husbandry, and Fisheries.

In India, 80% of the population lives in rural areas. They are mainly depended on agriculture, livestock, and fisheries for their livelihood (FAO). According to the latest report (Food and Agriculture Organization of the United Nations, 2020), agriculture is the primary source of livelihood for 70% of the population in India, with 82% of farmers being small and marginal. Agriculture and allied sectors like animal farming, forestry, and fisheries accounted for 25.6 % of the GDP (gross domestic product) in 2019. The Livestock sector alone contributes 4.11% of GDP (CIA fact book). The Central Statistics Office (CSO) estimates that the value of output from the livestock and fishing industries combined, at current prices, was roughly Rs. 2,82,779 crores in 2007-2008, or about 31.6% of the value of the output of Rs. 8,94,420 crores from agriculture and related industries. The entire value of India's imports and exports of livestock and animal products in 2017 & 18 was Rs. 101.24 billion and Rs. 457.76 billion, respectively. According to the FAO, India is the primary producer of fresh staple foods. Due to the lockdown implemented to prevent coronavirus, all the sectors showed negative growth, but only the agriculture sector grew by 3.4%. The Government of India has initiated the development of the blue economy to promote animal husbandry, milk processing, and development. The government of India has started disease control programs for important livestock diseases (FMD, Brucellosis, PPR, and Classical swine fever) and zoonoses.

1.1.2 Livestock Population in India

According to the 20th Livestock Census 2019, the total livestock population in the country is 535.78 million, and there was an increase of about 4.6 %. The bovine population is 302.79 million which includes the total number of cattle (192.49 million), and buffalo (109.85 million) which has increased by 0.8% and 1 % over the previous census. The country's sheep population stands at 74.26 million, showing a growth of 14.1% compared to the last census, goat population is 148.88 million, which increased by 10.1% over the previous census. The total pig population is 9.06 million which declined 12.03% over the previous census and the overall number of poultry stands at 851.81 million, showing a growth of 16.8% compared to the previous census in 2012.

1.1.3 Livestock Population in Karnataka

In Karnataka, most of the rural people are involved in growing crops and agricultural activities. Karnataka encompass approximately 12.31 million hectares of land, constituting 64.6% of the overall land area. As per the 2001 census, 71% are farmers and agricultural labourers. In Karnataka, the livestock sector plays a significant role in the rural economy and provides an additional income source to rural farmers. According to the 20th livestock census, the total livestock population in the state is 29 million and there was an increase of about 4.70% in Karnataka over the 2012 livestock census. The cattle and buffalo population numbers remain the same as in the previous census. The total sheep population in Karnataka was 11.1 million, which showed an increase of 15.31% compared to the previous census. The total goat population in Karnataka was 6.17 million, with an increase of about 28.63% over the earlier census. The total pig population in the state was 0.32 million, with a 6.25% increase compared to the 2012 census.

1.2 Foot and Mouth Disease virus and serotypes in Karnataka

Foot and Mouth disease (FMD) is a highly contagious viral disease of domestic and wild cloven-hoofed animals, including cattle, buffalo, sheep, goats, pigs, water buffalo, and wild species (OIE, 2012). The disease is caused by Foot and Mouth Virus (FMDV) belonging to the family *Picornaviridae* and genus *Aphthovirus* (Belsham, 1993). The virus has seven serotypes, namely O, A, Asia-1, South Africa territory-1(SAT-1), SAT-2, SAT-3, and C (Domingo *et al.,* 2003). The outbreak of FMD was responsible for significant socioeconomic losses (Thompson *et al.,* 2002). The direct economic losses due to FMD in India were estimated to be Rs. 200 Billion (Venkataramanan *et al.,* 2005). Prevention and control of FMD is highly important in protecting the livestock industry and improving the livelihoods of animal-rearing farmers in developing countries where FMD is highly endemic (Venkataramanan *et al.,* 2005). The success of the disease control program depends on understanding the epidemiology of the disease, especially the spatial analysis of the disease pattern and spread (Bhattacharya *et al.,* 2005).

1.3 History of Foot and Mouth Disease

FMD was first recorded in the written description of the year 1546 AD. The existence of FMD was first reported in 1754 in Germany. In Great Britain, it was first recorded in 1839 and in the United States of America was reported in 1870 and later noticed in South America (Radostits *et al.,* 2000). Since 1872, FMD has not existed in Australia, and it has never happened in New Zealand (Bachrach, 1968). The early history of FMD in Africa and Asia is unknown, but in South Africa, the disease was recorded in 1892 officially (Pattnaik et al., 2012b). The first case of FMD in India was documented in 1864 when it occurred in all the regions of the country (Hegde *et al.,* 2014). Loeffler and Frosch in 1922 revealed the causal agent of FMD, later cross-immunity studies on cattle conducted by Valle'e and Carre's were the first to demonstrate the existence of two immunological serotypes of the FMDV. They were named based on the area of origin, O (Oise valley, France) and A (Allemagne, Germany). In 1926 Waldmann and Trautwein showed the existence of three more serotypes A, B, and C. These virus strains were compared, and it was discovered that A and B are the same as Valle'e and Carre's strains O and A, respectively, but strain C was different. Later in 1940, three more serotypes were found in Africa and named SAT1, SAT2, and SAT3 (Brooksby, 1958). The seventh virus serotype was identified in India from 1950 to 52 and named ASIA1(Dhanda *et al.,* 1957).

1.4 Foot and Mouth Disease Clinical signs, Disease cycle, and Transmission

a

b

c

d

Figure 1.1 *Clinical signs observed in Cattle affected with Foot and Mouth Disease: a. Mouth lesions b. Salivation in lactating animals, c. Painful blisters on the tongue d. Painful blisters interdigital space of feet (Source of Pictures: FMD Regional Center, IAH & VB, Bengaluru, Karnataka, India)*

The main clinical symptoms of FMD are high fever (104-105^0 F), salivation in lactating animals, and a significant drop in milk production. FMD can be identified by identification of painful blisters/ vesicles on the tongue, lips, and other tissues of the mouth, udder, teats, and interdigital space of feet (Alexandersen *et al.,* 2003). Weight loss, loss of appetite, quivering lips, and frothing of mouth, cows may develop blisters on teats and lameness in several animals. Occasionally, FMD can also infect humans (Bauer, 1997). There can be mouth lesions, salivation in lactating animals, and painful blisters on tongue and interdigital space of feet (Figure 1.1).

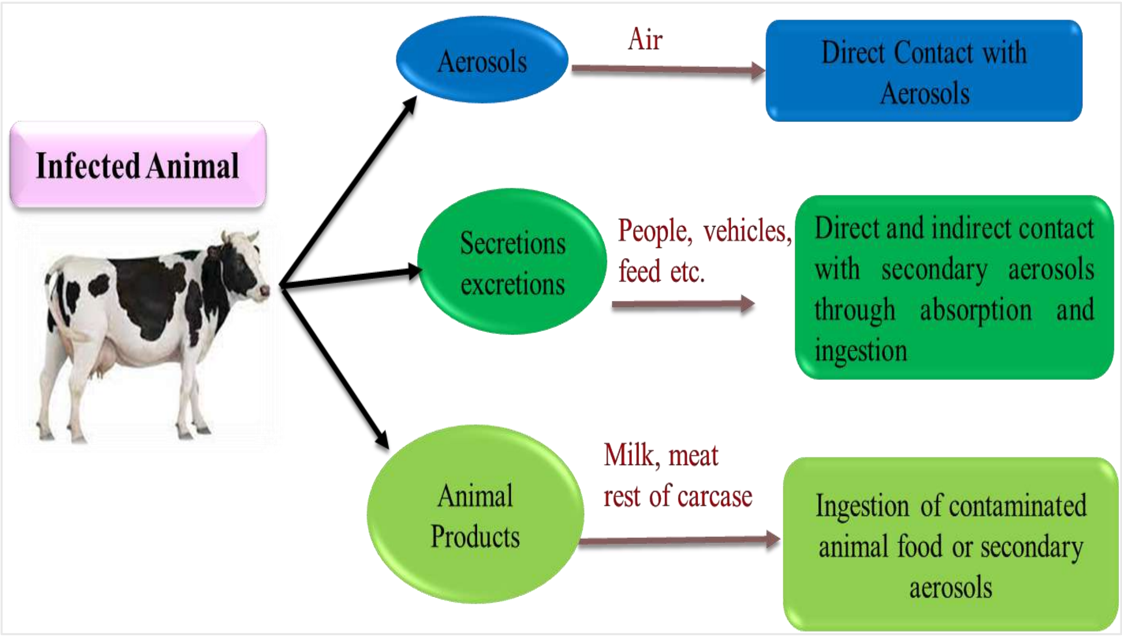

Figure 1.2 *Foot and mouth disease cycle and different methods of disease transmission.*

FMD is a viral disease and can spread rapidly between animals. The virus is excreted in the infected animal's breath, saliva, mucus, milk, and feces (OIE, 2012). Animals can excrete the virus for up to four days before the clinical signs appear (OIE, 2012). The disease can be transmitted in two ways: 1. Direct transmission and, 2. Indirect transmission. Direct transmission from animal to animal through air, saliva, mucus, and feces. An indirect method of transmitting through infected animal products, people, vehicles, etc, (Figure 1.2). The disease most commonly spreads through the movement of infected animals from one place to another. In sheep, symptoms may be absent or very mild and unidentifiable. Infected sheep can be an important source of infection.

FMD virus can also be spread through wool, hair, grass, or straw, by the wind, or by mud or manure sticking to footwear, clothing, livestock equipment like milking machines, etc (Singh SV *et al.,* 1992). The airborne transfer of droplets and droplet nuclei is probably the most frequent mode of transmission when infected and susceptible animals are nearby and long-distance airborne virus transmission depends on several factors, including the animal type, the quantity and position of the transmitting and recipient animals, and favorable geographical and meteorological conditions (Alexandersen *et al.,* 2003). In some situations, pigs are more resistant to an aerosol method of infection (Alexandersen *et al.,* 2002). Cattle are more susceptible to the disease and get infected by breathing small quantities of the virus. In some animals can be carried for long periods (months, years) after apparent recovery (Venkataramanan *et al.,* 2005).

1.5 Detection and Identification of the FMDV

The virus can be diagnosed in a lab with the proper level of biocontainment, based on risk analysis. The ELISA (Enzyme-linked immunosorbent assays) is used to find the FMDV antigen, and the serotype of the disease and LFD (Lateral flow devices) are used to find the FMDV antigen. The samples of milk, serum and heart muscles can also be tested using RT-PCR. The live virus is amplified using a reverse transcription polymerase chain reaction (WOAH, 2022b) (https://www.woah.org/en/disease/foot-and-mouth-disease/).

1.6 Economic losses due to Foot and Mouth Disease

The disease globally impacted the economic level of agriculture and industries in 2001 and affected tourism due to FMD outbreaks in the United Kingdom. Agriculture losses were 3.1-billion-pound string and tourism was 2.7- 3.2 billion-pound string (Thompson *et al.,* 2002). The FMD outbreaks were responsible for large socio-economic losses and GDP in the UK during 2001 was estimated at less than 0.2% (Thompson *et al.,* 2002). The global level disease control programme should follow the protocols developed by the FAO or OIE, to achieve the household level micro-economic benefit (Forman *et al.,* 2009). In developing countries, economic growth still depends on animal health conditions, and FMD is an infectious disease which is affecting the national economy and trade. In India, some studies were conducted to find the direct and indirect losses due to FMD (Pattnaik *et al.,* 2012b) stated that the anticipated annual direct financial impact of FMD in India is Rs. 20,000 crores. The total farm-level economic loss forecasted due to FMD in cattle and buffalo was $3159 million, $270 million and $152 million respectively. Direct losses of each component were forecasted for indigenous cattle, crossbred cattle, local and improved buffalo, as follows, range of milk loss/animal $ 6.87–47.44, 18.42–125.88, 16.33–91.43, and 27.17–123.62; mortality loss/animal ranged from $ 32.61–804.27, 30.76–577.7, 65.36–502.2, and 188.04–413.7; distress sale loss/animal ranged from $ 3.22–188.63, 64.34–519.3, 214.47–341.8, and 209.11–450.3; and the indirect losses like opportunity cost of labour/animal from $ 5.49–54.29, 5.49–67.78; 7.95–31.37 and 9.83–72.38 respectively. The lowest estimated draught power loss/animal ranged from $ 39.46 to $ 142.94, in Madhya Pradesh and the highest value was in Assam states (Govindaraj *et al.,* 2021). In the Kolar district, Karnataka state, India, investigated the impact of the foot-and-mouth disease (FMD) outbreak in cattle and buffaloes on the farming population. The results showed that the highest loss from FMD in indigenous cattle was the distress sale (208 $), and the highest loss from FMD in crossbred cattle was the mortality loss (515 $), which was then followed by the distress sale (490 $), milk yield loss (327 $), treatment cost (38 $), and additional labour engagement costs for nursing FMD-affected bovines (30 $). The average total loss per animal differed between native and improved buffaloes, with an average of $440 and $513, respectively (Govindaraj *et al.,* 2017).

1.7 Epidemiology and Spatial Distribution of FMD

Understanding the epidemiology of FMD is crucial in order to minimize its impact and effectively implement disease control measures (Pattnaik et al., 2012b). A susceptible-infected-recovered geographic automata model was used to estimate the deer spatial distribution on the predicted size and distribution of foot-and-mouth disease (FMD) outbreaks. The model was evaluated by comparing with unweighted pair group method with arithmetic mean (UPGMA) clustering and noticed significant difference in the estimated number of deer, the magnitude of FMD outbreaks and affected land area based on geostatistical estimation method (Highfield *et al.,* 2008). The Bayesian framework (MCMC) method is best suited when missing data is present (Deardon *et al.,* 2010). The objective was to assess the spatiotemporal distribution of FMD in cattle in northern part of Thailand using Space-time statistics which includes STP, Poisson and Bernoulli models to find the high-risk areas of FMD (Arjkumpa *et al.,* 2020). In India, efforts were made by researchers to know the spatial and temporal patterns of

FMD, but the patterns varied from time to time (Sharma, 2003; Sharma & Singh, 1993). The study was conducted in different parts of the country from 2006-2007 to 2010-2011, and the clinical samples were collected and analysis was carried out from cattle 17(94.5%) followed by buffaloes (3.3%), pigs (1.21%) and sheep (0.115%), and 1.4% of the samples were from semi-domesticated and wild animals including Mithun, Yak, Nilgai and Gaur. Major proportions (43%) of the total outbreaks were noticed in the Eastern region (states of Bihar, Orissa, West Bengal and Jharkhand) followed by 31.5% Southern region (states of Tamilnadu, Kerala, Karnataka and Andhra Pradesh), and North-eastern region (states of Assam, Manipur, Meghalaya, Mizoram, Arunachal Pradesh, Sikkim and Tripura) recorded 11.6% of the total incidence, Central region (5%) (Madhya Pradesh and Chattisgarh, Western (4.4%) (states of Rajasthan, Gujarat and Maharashtra) and lowest (4%) in Northern (states of Uttar Pradesh, Punjab, Haryana, Himachal Pradesh, Jammu & Kashmir and Uttarakhand). In September month the highest number of outbreaks was recorded and the lowest in June. No correlation was found between the density of FMD susceptible livestock population and the incidence of FMD. It was found that unrestricted animal movements is also contributing to spread FMD in the country (S Subramaniam *et al.,* 2013).

1.8 FMD Vaccination

There are seven FMDV serotypes present worldwide and vaccination against one serotype of FMDV may not protect against other FMDV serotypes and may not fully protect against different subtypes within the same serotype (Paton *et al.,* 2005). In 1926 First FMD vaccine was developed using formaldehyde-inactivated vesicular fluid collected from the infected calves by Vallee, Carre and Rinjard (Lombard *et al.,* 2007). Research continued and used the first inactivated adjuvanted vaccine in the field condition, the vaccine was developed by Waldmann in 1937, using formaldehyde for virus inactivation and aluminium hydroxide gel as adjuvant. Depending on the epidemiological conditions in a place or the perceived threat of virus introduction, foot-and-mouth disease vaccines are typically produced as mono- or poly-valent medicines. Thus, three or four serotype vaccines are extremely common, with some of them perhaps including two or three strains. In the year 1960 Pig kidney or Baby Hamster Kidney (BHK) cell culture was used instead of tongue epithelial culture to begin the industrial manufacturing of inactivated vaccines (Capstick *et al.,* 1962). In 1970s used the ethyleneimines and oil adjuvants for inactivation of FMDV (Brown *et al.,* 1963).

India is now producing and using a trivalent binary ethyleneimine (BEI) inactivated oil adjuvanted vaccine that contains serotypes O, A, and Asia1. In comparison to serotypes A and Asia1, vaccinations for serotypes O and SAT 2 need to carry higher antigen content (Doel, 2003; Parida, 2009)

1.9 Prevention and Control Strategies

A good strategy for controlling FMD is vaccination. Whereas, the present FMD vaccinations can protect animals against clinical infection, there is still a chance that virus replication in the oropharynx of sub clinically infected animals will cause ruminants to develop into carrier status (Parida, 2009). In India FMD is endemic in nature and the multiplicity of viral strains in circulation with serotypes O, A, and Asia 1, unrestricted movement of animals from diseased areas, and apparent infection in small ruminants have increased the disease situation in India (Pattnaik *et al.,* 2012). In developing countries, the best plan is to carry out repeated vaccination with other disease control measures. The Foot-and-Mouth Disease Control Programme (FMDCP) was started in the year 2003–04. Currently, FMD vaccination is carried out in all the districts of the country. Recently, disease occurrence, clinical disease severity, and outbreak frequency have all gradually and significantly decreased in areas receiving routine vaccinations, mainly under the FMD control programme and partially under the supervision of ASCAD (Assistance to States for Control of Animal Diseases) and RKVY (Rashtriya Krishi Vikas Yojona) of the Indian government. In Karnataka also, the vaccination in FMD severely affected districts was started from the year 2006-07 under ASCAD programme under this programme the animals are vaccinated once in a year. Later FMDCP was implemented in Karnataka in the year 2011 and increased the vaccination coverage. Cattles and buffalos are vaccinated every six months (August-September and February-March) under FMDCP, using a trivalent oil adjuvant vaccine that contains all three serotypes (O, A, and ASIA1) (Hegde *et al.,* 2014).

1.10 Statistical models and its uses

A statistical model consists of a series of mathematical equations that characterizes the behaviour of a subject of investigation in relation to random variables and their associated probability distributions. If the model has only one equation it is called a single-equation model, whereas if it has more than one equation, it is known as a multiple-equation model. A statistical model in mathematics is commonly represented as a pair (Y, P), where Y denotes the collection of potential observations and P represents the range of possible probability distributions on Y. It is assumed that there is a distinct element of P that generates the observed data. Through statistical inference, we can determine which element(s) in this set are likely to be the actual one. A model is a concise way of representing any system or perception of reality in a symbolic and simplified form (Campbell, 1988).

The goal of modelling is to understand reality mathematically. A model is considered a simplified representation of reality. Many complex interactions and results are depicted with simplicity to reach a decision. It is expected to be a good representation of those factors that influence production and management. Modelling has been used in natural sciences since, centuries in one way or the other. Models have been built in the physical, biological and social sciences. Various researchers have defined modelling in their own way viz.,

1. "Modeling is described as a representation of our so called 'real world' in mathematical terms", so that may gain a more precise understanding of its significant properties, which may hopefully allow some forms of prediction of future events.
2. Model is reality scaled down and converted to a form that can be comprehended.
3. A mathematical model is a model whose parts are mathematical concepts, such as constants, variables, functions, equations, inequalities etc.

Purpose of modelling:

1. Foremost among these is the need to predict new results, which may be in the form of an extension of existing results. Predictions often revolve around conditions that are likely to occur in the future, while on the contrary, there may be predictions regarding events for which obtaining direct experimental evidence is unfeasible.
2. Not all situations are simulated for this purpose. In certain cases, it suffices to describe the functioning of the system mathematically to gain a better understanding.
3. Not all situations are modelled for this purpose. In certain scenarios, a more profound understanding can be acquired by employing mathematical approaches to articulate the functioning of the system. Many great physical theories do this, although they make predictions as well. What is not usually involved in such descriptions is an element of control.

4. Indeed, many models used in research on foot-and-mouth disease are intended to help management for developing plans for disease prevention and control.

1.11 Aims of the study

The thesis aims to identify spatial risk factors, mapping of disease risk, managemental risk factors and serotype mapping that are influencing on the occurrence of Foot and mouth Disease across Karnataka, using statistical models.

1.12 Objectives of the study

The main objectives of the study are mentioned below:

1. Identification of district-level spatial risk factors for occurrence of Foot and Mouth Disease.
2. Development of high-resolution village level spatial risk map for Foot and Mouth Disease in Karnataka.
3. Identification of Managemental Risk Factors for occurrence of FMD in Karnataka Using Statistical Methods.
4. Spatial Mapping of FMD serotypes in Karnataka.

1.13 Significance of the study

Since the disease is endemic in all the districts of the state, it is necessary to find the risk factors for the disease in these areas by employing an appropriate statistical model. Modelling and risk mapping will help policymakers utilize the available resources in the form of vaccines, funds, and human resources judiciously to fight against the disease to prevention and control disease.

1.14 Limitations of the study

Since all statistical research are subject to certain limitations, this study is not an exception and those are given below:

1. Data used in this study is only based on secondary data to find the district level risk factors and risk mapping and for the managemental risk factor study collected the primary data using the structured questionnaire method.
2. The area of the study was restricted to the state level as it not in the scope of the study for all the states of India. However, the analyses presented can be extended to other states of India.

1.15 Research Gaps

There are many research gaps in understanding the epidemiology of FMD in India due to many factors, such as studies on how the virus circulates among wildlife and domestic animals. In addition, vaccines may not cover emerging strains of the virus or provide durable immunity. Existing studies on Foot and Mouth Disease (FMD) often rely on aggregated or low-resolution spatial data, which can obscure local-level patterns of disease transmission. There's a need for high-resolution spatial mapping using Geographic Information Systems (GIS) and remote sensing to capture finer spatial details. Remote sensing technology has been less utilized in FMD research, particularly in capturing environmental factors like land use, vegetation cover, and climate variables that may influence the spread of the disease. Traditional statistical models may not fully capture the complex spatial and temporal dynamics of FMD. There is a gap in applying novel statistical models, such as Bayesian hierarchical models or machine learning approaches, that can better account for spatial autocorrelation and non-linear relationships. There are few studies to identify local risk factors in occurrence of FMD in India, especially Karnataka, while FMD has been extensively studied globally, there is a specific gap in research focusing on the Karnataka region of India. The region's unique socio-economic, climatic, and livestock-rearing practices necessitate a localized study to inform regional control strategies.

1.16 Rationale of the study

High-resolution spatial mapping of FMD using GIS and remote sensing will provide critical insights into disease hotspots, aiding in targeted interventions and resource allocation. This will improve the effectiveness of FMD control programs in Karnataka. The application of novel statistical models will enhance the predictive accuracy of FMD outbreaks by accounting for complex spatial and temporal dynamics. This will enable better forecasting and proactive management of the disease. By integrating data from multiple sources, including remote sensing, the study will provide a comprehensive understanding of how environmental factors (e.g., climate, vegetation) and socio-economic factors (e.g., livestock density, market access) influence FMD spread. This understanding is crucial for designing context-specific interventions. Karnataka, with its unique landscape and livestock management practices, requires a localized approach to FMD control. This study will address the specific needs of the region, providing actionable insights for policymakers and stakeholders in Karnataka. While focusing on

Karnataka, the methodologies and findings of this study will have broader implications for FMD research globally, particularly in regions with similar agroecological settings. The integration of GIS, remote sensing, and advanced statistical models could serve as a template for similar studies in other parts of the world.

The study on spatial mapping of Foot and Mouth Disease in Karnataka using GIS, remote sensing, and novel statistical models is necessary to fill existing research gaps. It will provide critical insights into the spatial dynamics of the disease, improve predictive capabilities, and offer region-specific solutions for effective disease control. This research will not only benefit Karnataka but also contribute to the global understanding and management of FMD.

1.17 References

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Chapter 2

Identification of factors responsible for spatial variation of Foot and mouth disease outbreaks in Karnataka using statistical models

2.1 Introduction

Foot and Mouth disease is listed A as per World Animal Health Organization (WOAH) (Pawar *et al.,* 2010). FMD is an acute, highly contagious disease of cloven-footed animals that can result in economic loss due to high mortality in young animals, high morbidity in adults due to loss of milk and meat production (Upadhayay & Ewam, 2012; Verma *et al.,* 2010). The disease can affect the livestock industry due to restrictions in international trade (Pattnaik *et al.,* 2012). The detailed introduction about the disease was presented in chapter 1.

In this study, it was aimed to identify the district-level risk factors influencing the occurrence of FMD in Karnataka state. Foot and Mouth disease virus (FMDV) is a single-stranded, Positive sense RNA virus that causes the disease (Knowles & Samuel, 2003). FMDV is genetically diverse, with seven serotypes are O, A, Asia-1, South Africa territory-1 (SAT-1), SAT-2, SAT-3, and C distinct serotypes displaying high levels of antigenic variation and no immunologic cross-protection among serotypes (Bachrach, 1968; Domingo *et al.,* 2002; Sobrino *et al.,* 2001). Three of the Seven serotypes of the Foot and mouth disease virus remain endemic in India (O, A, and Asia-1), but serotype C has not been seen since 1995 (Pattnaik *et al.,* 2012). Cattle, Pigs, sheep, and goats, as well as numerous wild ruminant species, are all affected by the virus (Alexandersen & Mowat, 2005). The disease is transmitted mostly by direct contact, through the deposit of droplets or droplet nuclei (aerosols)in recipient animals' respiratory tracts (Alexandersen *et al.,* 2003b). FMD can also be transmitted via fomites. The incubation period of FMD ranges from 2-14 days, depending on the virus strain and dose, the mode of transmission, the animal type, and the husbandry settings (Alexandersen & Mowat, 2005). According to (Charleston *et al.,* 2011), the infectious period in cattle is only 1.7 days, and animals are not infectious until 0.5 days after clinical indications begin. Any animal from which FMDV can be recovered in oropharyngeal scraping for a period greater than 28 days post-challenge is considered as a carrier animal (Sutmoller *et al.,* 1968). More than half of FMD-free ruminants may become viral carriers. Except for a single report showing pigs as carriers, pigs normally clear the virus after 3 to 4 weeks of infection and do not become carriers (Alexandersen *et al.,* 2003b; Mezencio *et al.,* 1999; Parida, 2009). The influence on animal productivity and welfare, as well as household and national economy, foot and mouth disease (FMD), remains one of the most important livestock diseases in the world (James & Rushton, 2002; Perry & Rich, 2007). From 2003- 2004, the Government of India (Department of Animal Husbandry, Diary, and Fisheries) has been conducting a systematic vaccination-based control program to control and eventually eradicate FMD from India. Due to the diversity of circulating viral strains, unrestricted animal mobility, and asymptomatic or subclinical infection of primarily small ruminants, the disease situation in India is difficult. In India, a vaccination-based FMD control programme (FMD-CP) is being implemented with the goal of creating FMD-free zones. The programme involves biannual vaccination of all cattle and buffaloes in selected areas, followed by regular active surveillance and antibody monitoring in the vaccinated population (Pattnaik *et al.,* 2012). The main methods of disease control are vaccination and restriction of animal movement. The progressive control pathway (PCP), a tiered method for the control of FMD in endemic settings, is recommended by the World Organization for Animal Health and the Food and Agriculture Organization of the United Nations (OIE/FAO) (Sumption *et al.,* 2012). To eradicate the disease, America (Sutmoller *et al.,* 2003) and several other countries have implemented stamping out and severe zoo sanitary measures. FMD related losses have greatest impact in developing nations, which house two-thirds of the world's FMDV susceptible cattle and have a higher proportion of people who are financially and nutritionally dependent on livestock production (Baluka, 2016; Knight-Jones *et al.,* 2016). Most of the developed countries are free from FMD whereas the disease is endemic in Africa, the Middle East, and Asia. However, the disease is a global concern due to the increased Movement of livestock as well as trade in livestock products as a result of the globalized economy (Perry & Rich, 2007). Foot and Mouth disease-related production losses, such as decreased milk supply, can be significant and may persist even after clinical indications have faded (Kitching, 2002). FMD is predicted to cause direct economic losses of USD 2.0-3.2 billion per year(Prabu *et al.,* 2004; Singh *et al.,* 2013; Venkataramanan *et al.,* 2006). Indirect losses as a result of trade barriers will add to this total. FMD is a complicated issue in India, and various obstacles must be overcome in order to control and eradicate the disease. Among the challenges are the prevalence of several serotypes with the constant appearance of new variants, the unavailability of very effective and stable vaccinations, the enormous population, the species interface, and the insufficient number of educated workers. Furthermore, due to socio-economic concerns, the test and kill policy is not being explored in India (Pattnaik *et al.,* 2012). The spatial statistical and GIS-based methods play a major role in the analysis of animal disease. The method plays a significant role in both ecological and disease surveillance studies (Lawson & Zhou, 2005). FMD outbreaks still occur annually in Karnataka despite of FMD control measures including, regular vaccination of livestock (i.e., cattle, buffalo, and small ruminants). A study conducted in California enhanced the current understanding of the transmission of FMD by estimating contact rates of FMD in livestock (Bates *et al.,* 2003).

Different statistical and mathematical models are used to find the risk factors, and some of the related studies are mentioned, the Generalized linear mixed models are a more adaptable approach to analyse the non-normal data when random effects are present. Conducted study in 12 dairy cattle farms in Saudi Arabia from 1988 to 1993. A mathematical model was developed using vaccine trail data, the model showed that 95 % of the antibody having the having half-life of 43 days. SLIR epidemiological model was fitted to farm record data and it represented only the disease transmission rate. They concluded that the interval of inter-vaccination will provide more herd immunity (Woolhouse *et al.,* 1996). A mathematical model to forecast the disease incidence of hepatitis E in Shanghai, China. They considered morbidity data of hepatitis E For developing the model, data were obtained from the China Information System for Disease Control and Prevention in Shanghai from 2000 to 2012 (Ren *et al.,* 2013). The present research aims at developing statistical models for spatial variation. In the study, investigate the influence of environmental factors on the occurrence of Foot and Mouth disease. In India, FMD disease is endemic and occurs throughout the country with larger number of cases being reported from Southern and Eastern states Hence, the state of Karnataka has been chosen as the study area to find the main risk factors which are influencing on occurrence of FMD outbreaks using statistical models.

2.2 Materials and Methods

2.2.1 Study area

Karnataka is the largest state in south India and the seventh-largest state in India. Based on the area it is the sixth-largest state in India (191,976 Square kilometres or 5.83 % of the total geographical area of the country) and based on the population Karnataka is the eighth-largest state in India, comprising 30 districts. Karnataka is situated in the southwestern region of India. Karnataka is located approximately between 11.30°N and 18.30°N latitudes, 74°E and 78.30°E longitude in the center of western peninsular India. There are three distinct geographical regions in Karnataka viz., the Deccan Plateau, the Western Ghats, and the Coastal Plains. The Arabian Sea and the Laccadive Sea, Goa on the Northwest, Maharashtra on the North, Andrapradesh on the East, Tamilnadu on the South East, and Kerala on the South West bordered Karnataka on the west. It has a 350 km long coastline, which is the western boundary. The average annual rainfall here is approximately 1335 mm. There are 30 revenue districts in Karnataka. Based on (a) Rainfall pattern, quantum, and distribution, (b) Soil type, texture, depth, and physicochemical properties, (c) Elevation and topography, and (d) Major crops and types of vegetation Karnataka is divided into 10 Agro-climatic zones. They are (1) North-eastern transition zone, (2) North-eastern dry zone, (3) Northern dry zone, (4) Central dry zone, (5) Eastern dry zone, (6) Southern dry zone, (7) Southern Transition Zone, (8) Northern transition zone, (9) Hilly zone, and (10) Coastal zone (KTK 2022). The districts of Karnataka are depicted in Figure 2.2.1.

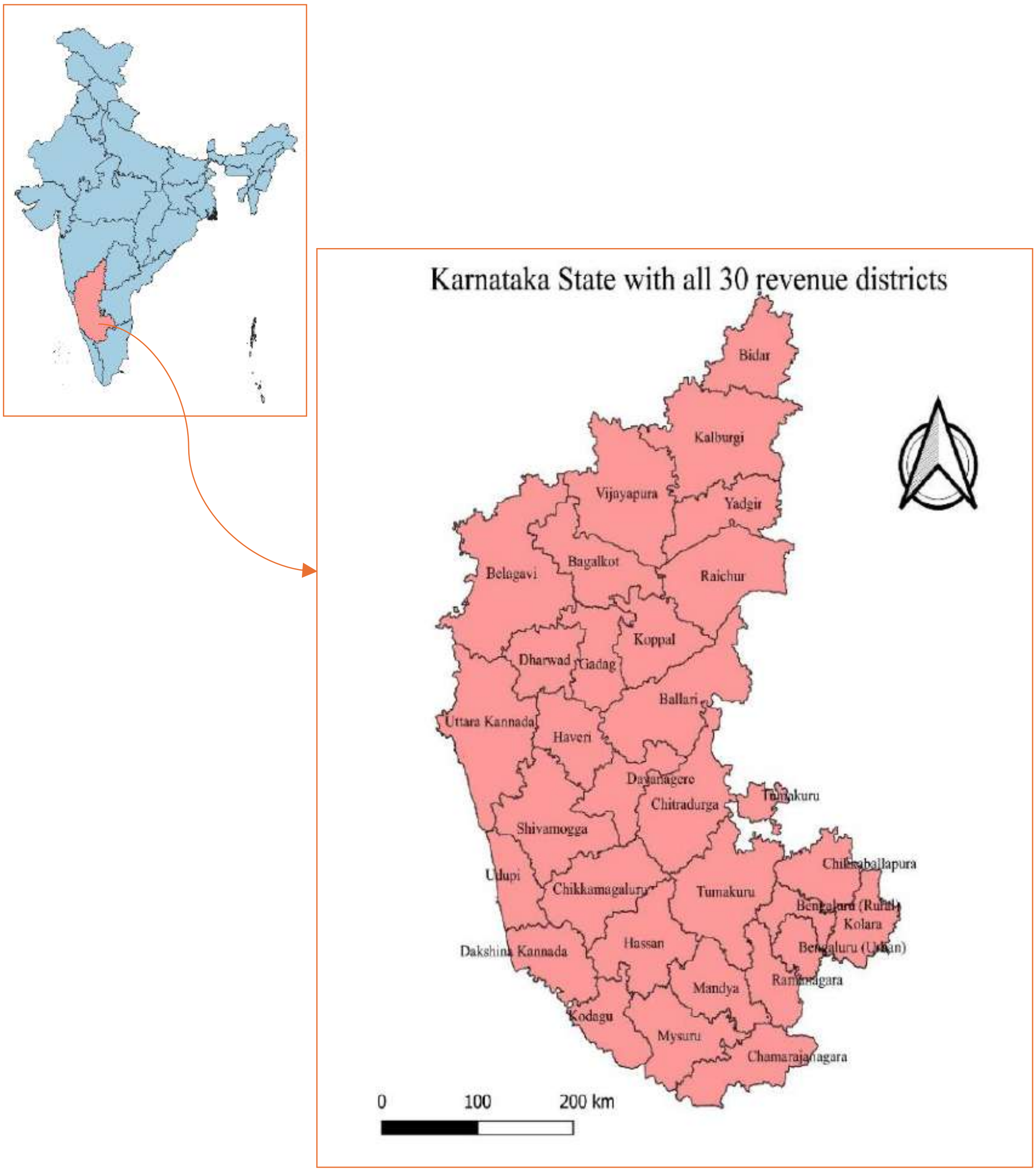


Figure 2.2.1 *Karnataka state of all the 30 revenue districts for the study*

2.2.2 FMD outbreak data

Data on district level FMD outbreak from 1977 and 2014 were obtained from the Department of Animal Husbandry and Veterinary Services, Government of Karnataka, Hebbal, Karnataka, India.

2.2.3 Livestock data

According to the 19th livestock census data in Karnataka, 29.0 million livestock population present which includes 8.9 million cattle, 3.0 million buffalo, 11.1 million sheep, 6.2 million goats, and 0.3 million pigs (Source: AHVS, GOK, 2019). The area covered by each district in square kilometres was collected from the website (https://villageinfo.in/karnataka.html). Density of cattle, buffalo, sheep, goat and pigs was estimated for all the 30 districts of Karnataka state and used in further analysis.

2.2.4 Environmental data

The Remote sensed variables were obtained from the MODIS (Moderate Resolution Imaging Spectroradiometer) at 1 Km spatial resolution (Scharlemann *et al.,* 2008). Remote sensed variables are described in terms of the mean, minimum and maximum, amplitudes, and phases of the annual, bi-annual, and tri-annual. Remote sensed variables included were Middle Infra-Red, daytime and nighttime Land Surface Temperature, Normalized Difference Vegetation Index, and Enhanced Vegetation Index (EVI). QGIS 13.14.15 Software as used to make spatial FMD distribution map. SPSS (Version 21) for all statistical analyses.

2.2.5 Statistical Analysis

2.2.5.1 Descriptive statistics

Descriptive statistics encompass the type of information that can be conveyed in a few words, providing a brief overview of the fundamental characteristics of the data in a study, such as the mean and standard deviation (Sundaram KR, 2014). In our study, data was collected and summarized into, Numbers, Mean, Standard deviation and variance further the summarized data was used to develop the choropleth map of the disease. Before analysis of the data, it is important to know the quality of the data. The quality of data depends on certain assumptions, such as the normality of continuous data. To assess the normality of data, different techniques are utilized, including numerical and visual methods. Each method possesses its own set of strengths and weaknesses

(Altman & Bland, 1995). The scientific analysis of data relies on the utilization of both descriptive statistics and inferential statistics, as they hold equal importance in the field of statistics and also checked the normality of the predictor variable to draw the inference from the data. This was carried out by studying FMD in Karnataka for a period of 37 years (from 1977 to 2014) shown in (Table 2.3.1).

2.2.5.2 Stepwise Regression Analysis

Selection of the predictor variables (Xi) was performed using stepwise regression analysis method (Olusegun *et al.,* 2015).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$$

Where,

Y=Foot and mouth disease outbreaks (dependent) variable,

β_0 =Intercept,

β_1, β_2, ………, β_n = Estimated regression coefficients.

X_1, X_2, ……, X_n = Remote sensed variables and density of livestock (predictor) variables

In variable selection procedures, stepwise regression analysis is one method. In stepwise regression analysis, there are four methods namely forward (step-up) selection, backward (step-down) selection, stepwise selection and Min MSE (Mean Square Error). In this study, used stepwise selection criteria to select the predictor variables from the 32 remote sensed variables and density of the all the animal species in Karnataka (cattle, sheep, goat, and buffalo). based on the R^2 value.

2.2.5.3 Poisson regression model

The variables selected in variable selection method were used in fit a Poisson regression model. The Poisson distribution assumes that the conditional mean and variance are equal, i.e. that the data are evenly distributed (Gupta & Kapoor, 2009).

A random variable X is said to follow a Poisson distribution if it assumes only non-negative values and its probability mass function is given by

$$P_{po} = \left(Y_i = \frac{y_i}{x_i}\right) = \frac{e^{-\lambda}\lambda^{y_i}}{y_i!}\ , y_i = 0,1,2, \dots \dots, \quad \lambda > 0$$

Here, λ is known as the parameter of the distribution. The notation X~P(λ) will be used to denote that X is a Poisson variate with parameter λ.

With mean and variance given by

$$E\left(Y_i = \frac{y_i}{x_i}\right) = V\left(\frac{y_i}{x_i}\right) = \mu_i = exp\left(x_i'\beta\right)$$

$$Log(\mu_i) = x_i'\beta$$

2.2.5.4 Negative Binomial regression model

The Negative binomial distribution is an alternative to the Poisson distribution that is particularly effective for count data with over-dispersion (variability present in the data) and when the sample variance is greater than the sample mean.

A random variable X is said to follow a Negative Binomial distribution with parameters r and p if its probability mass function is given by,

$$P_{nb}(X = x) = p(x) = \binom{x + r - 1}{r - 1} p^r (1 - p)^x \quad x = 0,1,2 \ldots .\ 0,$$

otherwise,

With Mean $E\left(\frac{y_i}{x_i}\right) = \mu_i = exp\left(x_i'\beta\right) = rP$

With Variance $V\left(\frac{y_i}{x_i}\right) = \sigma^2 = \mu_i(1 + \alpha\mu_i) = rPQ$

Therefore, As $Q > 1$, Mean < Variance, i.e. $rP < rPQ$, which is a distinguishing feature of the Negative Binomial distribution.

2.2.5.5 Justification for selection of Poisson and Negative binomial regression Models.

In the study of Foot and Mouth Disease (FMD) at the district level, the choice of statistical models is crucial for accurately identifying and quantifying the risk factors influencing the occurrence of the disease. The selection of appropriate models depends on the nature of the data and the specific objectives of the study. Here’s a rationale for choosing Poisson and Negative Binomial regression models. FMD occurrence is typically measured as the count of cases within a district over a specific time period. Count data is inherently non-negative, discrete, and often skewed, making linear regression models inappropriate. In epidemiological data, the variance often exceeds the mean, a phenomenon known as overdispersion. This needs to be accounted for in the model selection to avoid biased estimates and incorrect inferences. Different districts may have varying levels of disease risk due to differences in environmental factors and livestock density. Models must be able to accommodate this variability.

Poisson regression is designed for modeling count data, where the response variable represents the number of occurrences of an event, such as the number of FMD cases in a district. Poisson regression assumes that the mean and variance of the count data are equal. This assumption is appropriate when the data exhibits no or limited overdispersion. The Poisson model is relatively simple and provides easily interpretable results, where the coefficients indicate the change in the log of the expected count of FMD cases for a one-unit change in the predictor variables. Sometimes, if the variance in the data significantly exceeds the mean, the Poisson model might underestimate the standard errors, leading to overly confident statistical inferences (Type I error). This is where the Negative Binomial model becomes more appropriate.

The Negative Binomial regression model is an extension of the Poisson model that introduces an additional parameter to account for overdispersion. This makes it more flexible and appropriate for real-world epidemiological data where overdispersion is common. The Negative Binomial model reduces to the Poisson model when the overdispersion parameter is zero, making it a more general model that can adapt to different levels of data dispersion. By accounting for overdispersion, the Negative Binomial model provides a better fit to the data, leading to more accurate estimates of the effects of district-level risk factors on FMD occurrence. This model is robust to violations of the mean-variance equality assumption, ensuring more reliable results in studies with high variability in disease counts across districts (Gupta &Kapoor 2009).

2.3 Results

In Karnataka, all the 30 districts have reported FMD during the study period. There were 10527 outbreaks reported during the period 1977-2014. The maximum number of FMD outbreaks (n=1566) was observed in the year 2006. Belagavi district reported maximum number of outbreaks (n=806) followed by Tumkur (n=779), Davangere (n=721), Haveri (n=712), Shivamogga (n=675), Chitradurga (n=647), Kolar (n=578), Hassan (n=560), Raichur (n=527), Kalburgi (n=513), Dharwad (n=473), Chikkamagaluru (n=456), Mysuru (n=454), Koppal (n=363), Bangalore Urban (n=349), Bangalore Rural (n=328), Mandya (n=278), Uttara Kannada (n=215), Bagalkot (n=204), Vijayapura (n=168), Bellary (n=138), Chikkaballapura (n=137), Kodagu (n=132), Yadgir (n=69), Bidar (n=68), Gadag (n=58), Chamarajanagara (n=55), Ramanagara (n=32), Dakshina Kannada (n=22) and Udupi (n=10) reported least number of FMD outbreaks during the study period (Figure 2.3.1 and Table 2.3.1). Maps to show the distribution of FMD outbreaks is shown in terms of total number (Figure 2.3.2 a), mean (Figure 2.3.2 b), Standard deviation (Figure 2.3.3c) and variance (Figure 2.3.4d). Mean FMD outbreaks were categorized into Very high (>17), High (12.8-17), Medium (8.6-12.8), Low (4.5-8.6), and Very low (<4.5). According to the magnitude of outbreak Belagavi, Haveri, Shivamogga, Davangere, Chitradurga and Tumkur districts belongs to a very high category, Kalburgi, Raichur, Kolar, and Hassan comes under the high category, Dharwad, Chamarajanagara, Koppal, Mysore, and Bengaluru (Urban) comes under the medium category, Bagalkot, Uttarakannada, Mandya and Bangalore (rural) belongs to a low category and all other districts under very low category (Figure 2.3.3).

Buffalo density and bi-annual phase of NDVI were the two predictor variables selected in the step wise variable selection based on the R^2 value. The selected predictor variables were used to fit Poisson and negative binomial regression models. Negative binomial regression model was the better model (AIC=411.27) compared to Poisson regression model (AIC=4656.72). In the negative binomial regression model, buffalo density and biannual phase of NDVI were positively associated with occurrence of FMD outbreaks (Table 2.3.3). The distribution of FMD outbreak, Buffalo density, and Bi- annual phase of NDVI are shown in (Figures 2.3.3 to 2.3.5).

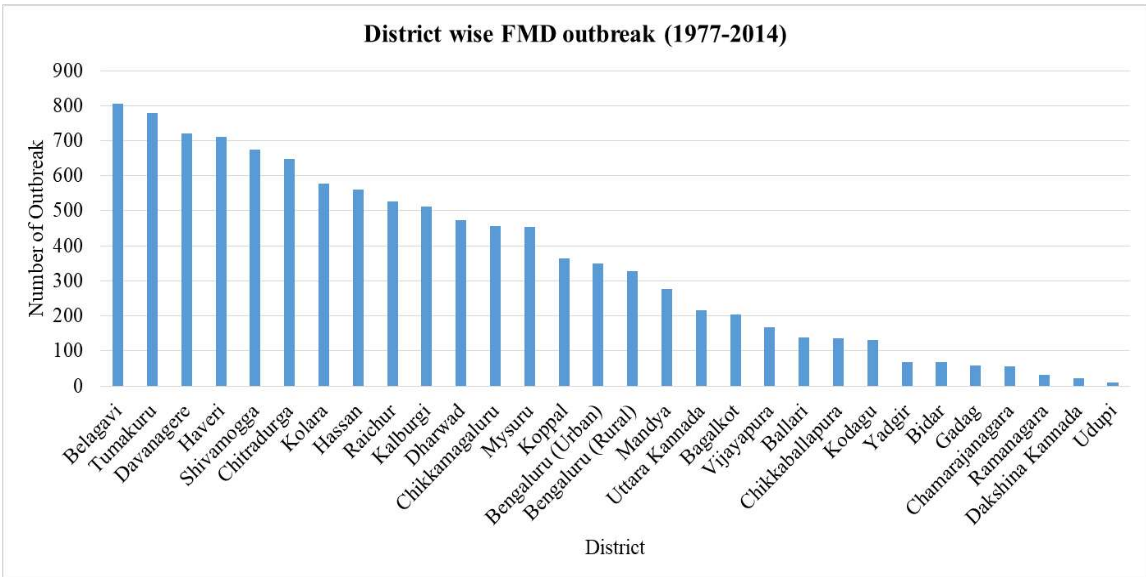
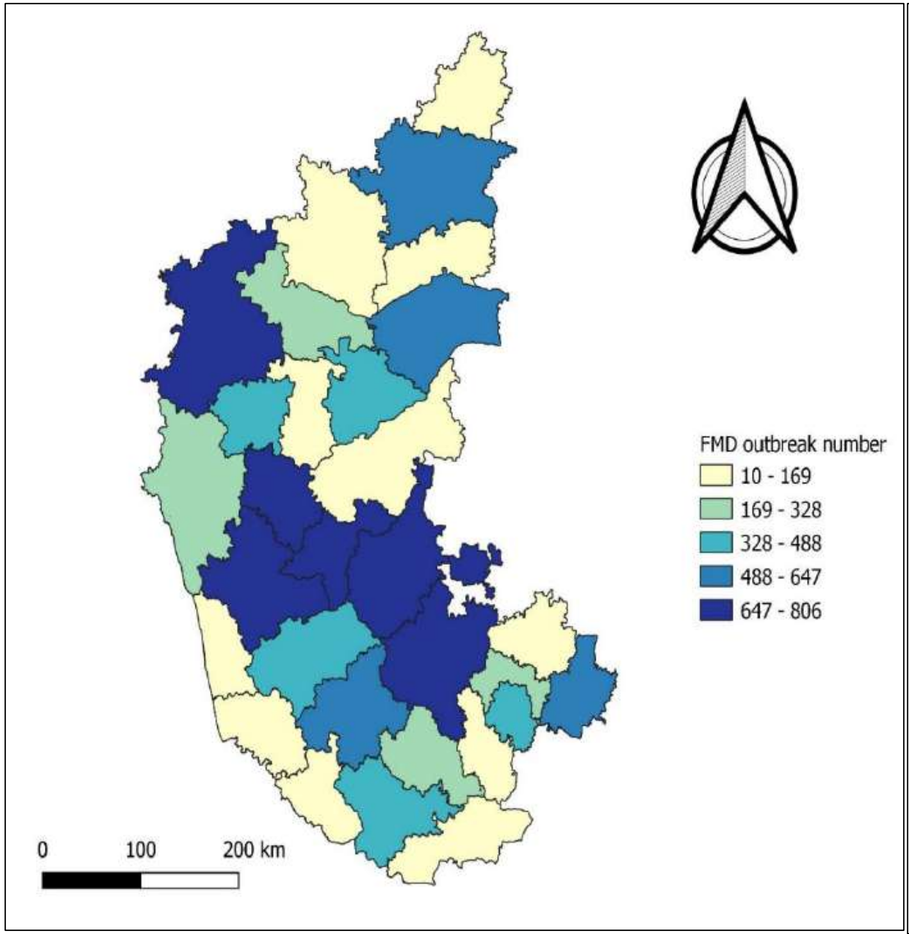
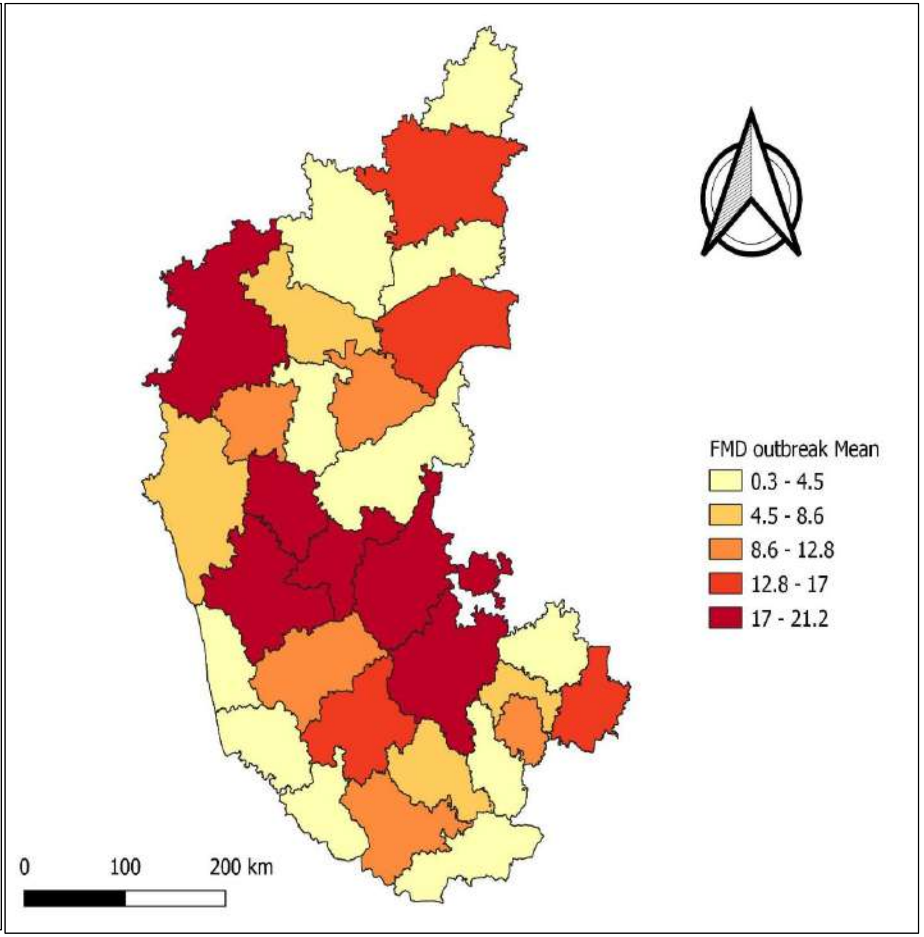


Figure 2.3.1 *Bar diagram for district wise FMD outbreaks (1977-2014)*

Table 2.3.1 *District-wise FMD outbreak and percentage (1977-2014)*

District	FMD Outbreak Number	% of FMD Outbreak
Belagavi	806	7.66
Tumakuru	779	7.40
Davangere	721	6.85
Haveri	712	6.76
Shivamogga	675	6.41
Chitradurga	647	6.15
Kolara	578	5.49
Hassan	560	5.32
Raichur	527	5.01
Kalburgi	513	4.87
Dharwad	473	4.49
Chikkamagaluru	456	4.33
Mysuru	454	4.31
Koppal	363	3.45
Bengaluru (Urban)	349	3.32
Bengaluru (Rural)	328	3.12
Mandya	278	2.64
Uttara Kannada	215	2.04
Bagalkot	204	1.94
Vijayapura	168	1.60
Ballari	138	1.31
Chikkaballapura	137	1.30
Kodagu	132	1.25
Yadgir	69	0.66
Bidar	68	0.65
Gadag	58	0.55
Chamarajanagara	55	0.52
Ramanagara	32	0.30
Dakshina Kannada	22	0.21
Udupi	10	0.09


FMD outbreak number
10 - 169
169 - 328
328 - 488
488 - 647
647 - 806
0
100
200 km


FMD outbreak Mean
0.3 - 4.5
4.5 - 8.6
8.6 - 12.8
12.8 - 17
17 - 21.2
0
100
200 km

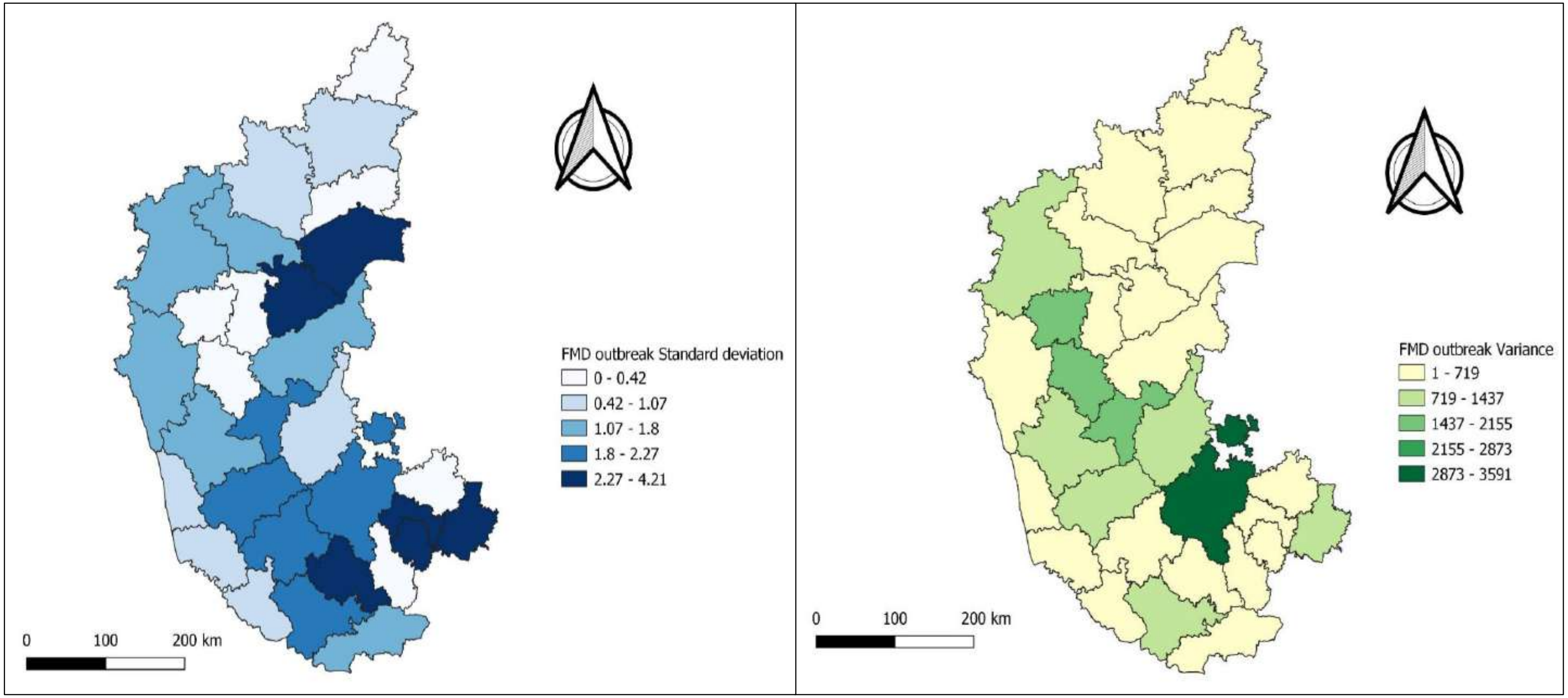


Figure 2.3.2 *Spatial distribution of FMD outbreaks in Karnataka a) Sum of outbreaks b) Mean of outbreaks c) Standard deviation of outbreaks and d) variance of FMD outbreaks in Karnataka*

Table 2.3.2 *Estimated values of coefficients of Poisson regression model for FMD.*

Parameter	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
(Intercept)	5.062	.0233	5.016	5.107	47026.957	<0.001***
Buffalo density	0.023	0.0006	0.022	0.025	1321.531	<0.001***
Bi-annual phase of NDVI	0.243	0.0090	0.226	0.261	731.839	<0.001***

AIC =4656.72, AICC=4657.65, BIC=4660.93 and Pearson Chi-square =4303.89
Significant at 10%, * *Significant at 5%, * significant at 1%.*

Table 2.3.3 *Estimated values of coefficients of Negative binomial regression model for FMD.*

Parameter	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr >ChiSq**
(Intercept)	4.704	0.4837	3.756	5.652	94.560	<0.001***
Buffalo density	0.036	0.0201	-0.004	0.075	3.154	<0.076*
Bi-annual phase of NDVI	0.333	0.1873	-0.034	0.700	3.160	<0.075*

AIC =406.74, AICC=408.34, BIC=408.33 and Pearson Chi-square =10.928.
Significant at 10%, * *Significant at 5%, * significant at 1%.*

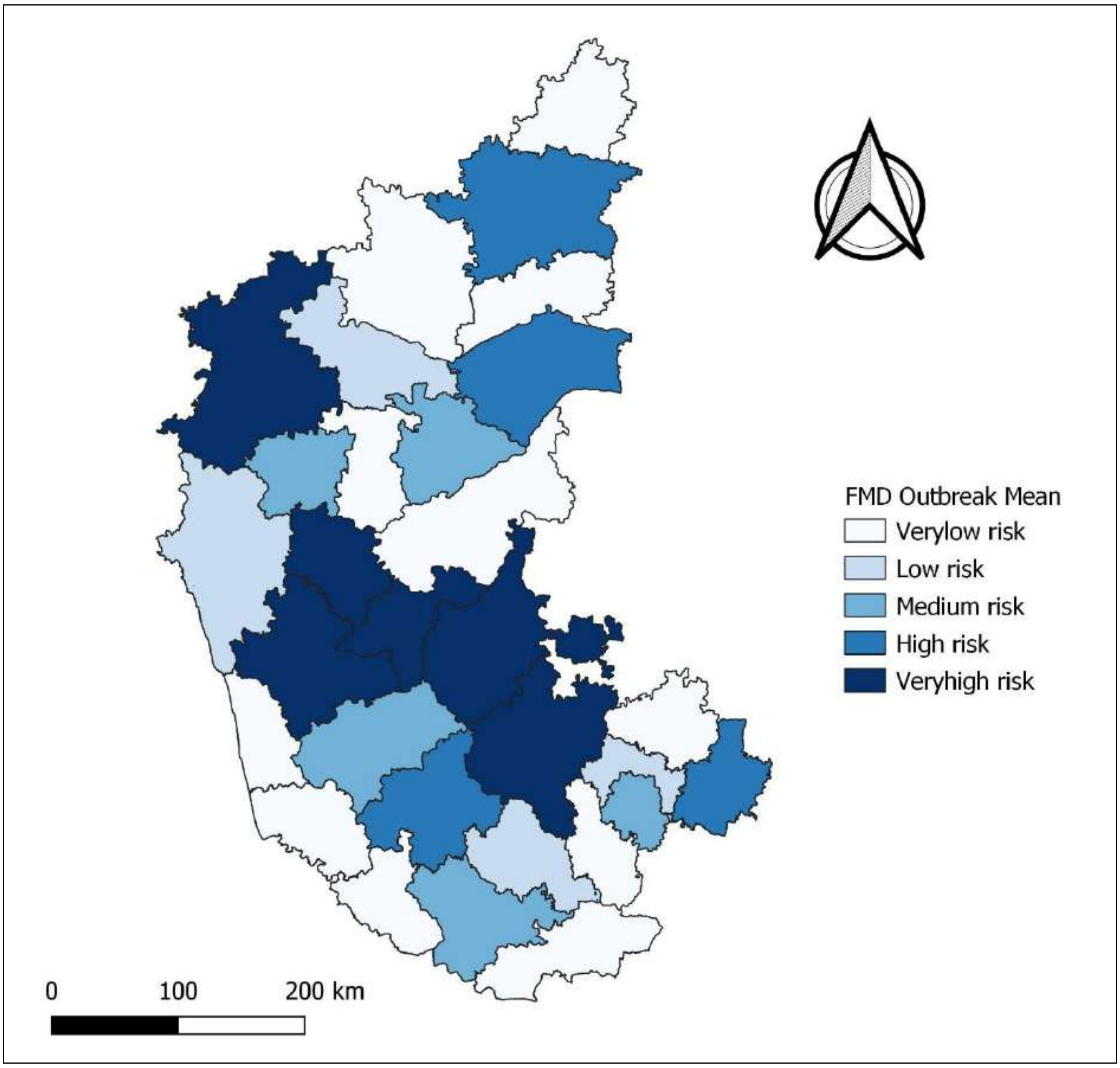


Figure 2.3.3 *Map showing district-wise distribution of FMD outbreaks in Karnataka*

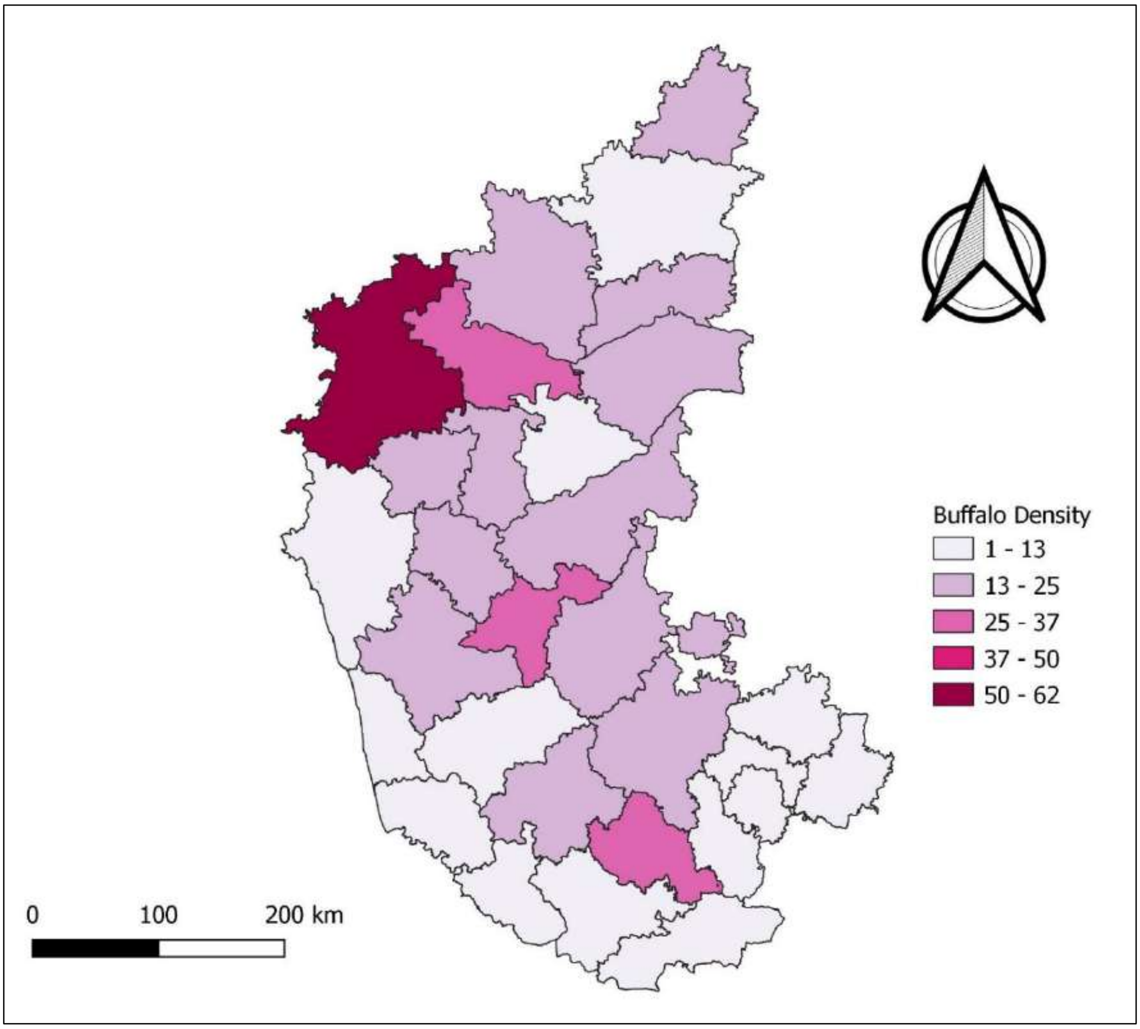


Figure 2.3.4 *Map showing district-wise distribution of density of buffalo in Karnataka*

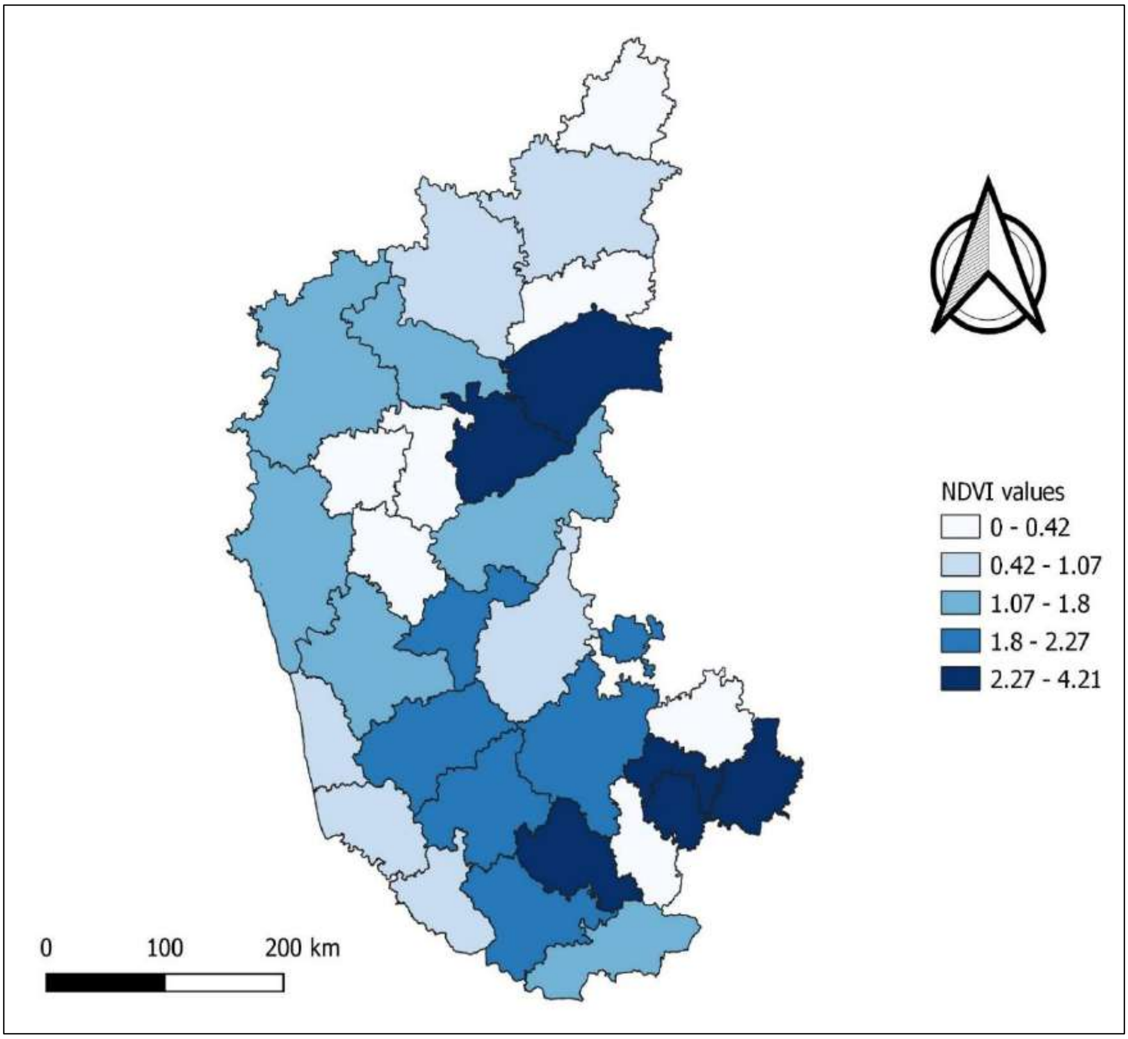


Figure 2.3.5 *Map showing district-wise distribution of bi-annual phase of NDVI in Karnataka*

2.4 Discussion

It was found that maximum number of outbreaks were reported from Belagavi district (n=806) of Karnataka. The stepwise regression analysis used to find the major influencing factors on the occurrence of FMD disease in Karnataka. Negative binomial model was better model compared to the Poisson model. Density of buffalo and bi-annual phase of NDVI was significant in determining the spatial variation of FMD outbreaks in Karnataka. There is a spatial variation in the occurrence of FMD in Karnataka. The factors responsible for variation in occurrence of the disease will vary depending on the geographical region studied. Winter season and the geographical conditions were favourable to the airborne spread of FMD in the upper Midwestern region of the United States (Hagerman *et al.,* 2018). Temperature and rainfall were main risk factors for airborne spread of disease (Hagerman *et al.,* 2018).Although this study was conducted amidst a period of extreme drought, characterized by hot and dry weather conditions, meteorological information from the KNP indicates that, during nighttime, temperatures and relative humidity, particularly in the winter season, are typically conducive to the survival of the FMD virus in aerosols(Gainaru *et al.,* 1986).. In a study in Bangladesh it was found that climate also plays a major role in the occurrence of FMD (Rahman *et al.,* 2020). Maximum entropy mode was used to assess the present and future geographical distribution of FMD and risk in elephants under climatic change and showed that average annual temperature and annual precipitation were contributes more for risk of FMD in elephants (82.8%) (Jiang *et al.,* 2020). Variable selection is important before to proceed with fitting a model in identification of risk factor. stepwise variable selection method used before fitting a model. The multiple Linear Regression (backward elimination) method was used to identify risk factors for malaria incidence in Tamil Nadu (Devi, 2003). Appropriate statistical methods are required to handle count data by accounting for over dispersion. Use of traditional regression models with Gaussian distribution is not advocated when the data is not normally distributed as it may create bias in estimating the co-efficient of the predictor variables. Identified density of buffalo and bi-annual phase of NDVI. Some of the similar studies mentioned here, buffalo act as carrier of Foot and Mouth disease, acutely infected buffalo effectively spread the infection to susceptible buffalo they come into direct contact with(Gainaru *et al.,* 1986). the study conducted in Kruger National Park of South Africa noticed African buffalo acts as a host of FMDV (Verin, 2011). The impact of Indian buffalo on FMD epidemiology, disease transmission, and immune response to vaccination has not been thoroughly researched. Previous studies have shown the transmission of FMD virus from infected cattle to susceptible buffalo, as well as the subsequent transmission of the virus from buffalo to susceptible goats (Dutta *et al.,* 1983). It is confirmed that buffalo can spread FMD through direct contact, and that vaccination is effective in preventing this spread.(Madhanmohan *et al.,* 2014). In India, it has been noted that Foot-and-Mouth Disease (FMD) is frequently apparent in cattle while remaining hidden in buffalo, posing challenges in determining the infection's origin and transmission source. Recent research indicates that buffalo can be infected just as easily as cattle, serving as a potential source of infection for both healthy cattle and buffalo through direct contact, as documented in the field (Gomes *et al.,* 1997). The study was to create seasonal spatial patterns of wildlife (utilizing the normalized difference vegetation index – NDVI – as an indicator of food availability) and assess the potential impact of seasonal variations on the potential transmission of FMD virus(Highfield *et al.,* 2009).

2.5 Conclusion

Identified the spatial risk factors in determining the district-level variation in FMD outbreaks in Karnataka, India. The spatial analysis of FMD outbreaks and the development of a risk map will help the policymakers to target vaccination in high-risk areas. This will help in the reduction of the economic burden of the disease on rural farmers.

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Chapter 3

Development of high-resolution village-level spatial risk map for Foot and Mouth Disease in Karnataka

3.1 Introduction

A spatial risk map of Foot-and-Mouth Disease (FMD) visually represents the potential risk or likelihood of FMD outbreaks in a given geographical area. It utilizes spatial data and analysis techniques to identify areas at higher risk and guide decision-making related to disease control and prevention measures. FMD is a highly contagious viral disease that affects cloven-hoofed animals such as cattle, pigs, sheep, and goats. Spatial risk mapping helps to identify regions or specific locations where the conditions are favorable for FMD transmission and outbreaks. By integrating various data sources and employing machine learning or statistical models, a spatial risk map can be generated to inform stakeholders about the areas where preventive measures should be prioritized or intensified.

3.1.1 Risk Mapping/Spatial Epidemiology

It is used to identify, assess, and visualize the potential risk areas associated with the risk factors. The Federal Emergency Management Agency provides an overview of risk mapping, assessment, and Planning programs. The principles and methodologies used in risk mapping include hazard identification, Risk assessment and the development of risk maps ((FEMA), 2016). It is possible to gain insight into the data and identify potential risk factors, in spatial epidemiology, this is called disease mapping (Berke, 2005). The spatial epidemiology focuses on three types of study, these include (i) disease mapping, (ii) disease clustering, and (iii) geographic correlation analysis (Elliot *et al.,* 2000). Spatial epidemiology focuses primarily on the analysis of two types of data: case-event data and summary data, which typically result in point maps and choropleth maps.

3.1.2 Georeferencing

Tomlinson is known as the "father of GIS". Roger Tomlinson pioneered the development and application of geographic information systems. His work laid the foundation for georeferencing techniques and spatial data analysis. The researcher suggested that GIS provides wealthy georeferenced data that can be used for modeling and the ability to process such data in geomodels. The aim is to combine the quantitative geographic methods of the 1950s and 1960s with his GIS capabilities of the 1990s (Tomlinson, 1989). The term "georeferencing" has several definitions. For example, (Wade & Sommer, 2006) defined georeferencing as "the alignment of geographic data to a known coordinate system so that it can be viewed, interrogated, and analyzed with other geographic data". (Zheng *et al.,* 2011) defined in more rigorous views include the study of georeferencing in multimedia and ways to identify geographic objects in general. Georeferencing refers to associating data (e.g. documents, data, maps, images, biographical data, objects) with geographic locations using place names and location codes (e.g. postal code) or geospatial references (e.g. longitude and latitude coordinates). The digital library's approach to georeferencing is a mix of geographic information systems (GIS) that focuses on geospatial coordinates, data layers, and mapping. The work of the map library in acquiring, cataloging and using cartographic publications and information; In a traditional library, the focus is on presenting text using place names, hierarchies of administrative units, and other textual forms of place references (Goodchild *et al.,* 2004). In a broader sense, it is about promoting spatial skill, "meaning the ability to spatially interpret problems and their solutions" in digital library applications (Parry, 2005). The researcher has given an overview of the challenges associated with georeferencing by introducing, classifying and exploring the field and its associated methods and applications (Hackeloeer *et al.,* 2014).

3.1.3 Machine Learning (ML)

Machine Learning approaches, which are based on the idea that systems can learn from data, identify patterns, and make decisions with very little human intervention, have had a tremendous impact on business and research due to their ability to address difficult issues. There are countless ML applications, such as computer vision (Chabot *et al.,* 2022; Sant'Ana *et al.,* 2022). Widely recommended especially for disease prediction and identification of the corresponding risk factors, it is clear that there are few publications where this method has been applied in veterinary medicine or where it shows if it is correct and useful. In one study it was found that neural network, logistic regression, linear regression, multiple regression, principal component analysis, and k-means methods were commonly used in peer-reviewed publications and machine learning applications is the emerging field of veterinary medicine (Cihan *et al.,* 2017). Machine learning (ML), one of the most rapidly developing subfields of artificial intelligence (AI) research, is defined as the research area of computer algorithms that are able to learn autonomously to automatically improve the performance of a task based on their own prior experience. The main goal of ML techniques is to allow the system to acquire knowledge without explicit programming and to learn from the data. Numerous scientific works have been devoted to the development of methods that allow machines to learn autonomously without being explicitly programmed (Mahesh, 2020). Machine Learning depends on different algorithms. The most important algorithms for regression problems are Linear regression, Logistic regression, Naive Bayes, Support vector machine (SVM), Decision tree, Random Forest (RF), K-nearest neighbours (K-NN), and Linear discriminant analysis (LDA). The unsupervised learning algorithms are K-means clustering and principal component analysis (PCA)(Micucci & Iula, 2022). The advantages of ML techniques are, that it require no distributional assumptions, no limit on the number of predictors, and no transformation of variables required (Goldstein *et al.,* 2017; Kuhle *et al.,* 2018).

3.2 Materials and Methods

The village level occurrence of FMD outbreaks from May 2020 to December 2021 was obtained from the Department of Animal Husbandry and Veterinary Services, Karnataka. The village wise list was prepared and the outbreak village names were matched with the village database of Karnataka state (https://vlist.in/state/29.html) (Georeferencing). There were a total of 234 villages that reported the FMD outbreak during the period. Remote sensed variables (MODIS) along with cattle and buffalo (FAO) populations were used in the analysis. Machine learning method was used to develop risk map in our study using R.

3.2.1 Binomial Logistic Regression Model

Binomial regression, also known as logistic regression, is a statistical modeling technique used when the dependent variable is binary or categorical (Agresti, 2012). It is commonly employed to analyze data where the outcome variable is dichotomous, such as "success" or "failure," "yes" or "no," or "0" or "1." The binomial regression model assumes that the probability of success (or the occurrence of an event) follows a logistic function. The logistic function maps any real-valued number to a value between 0 and 1, which represents the probability of success.

The general form of a binomial regression model can be represented as:

$$Log\ (\frac{p}{(1-p)} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p$$

where:

log(p/(1-p)) is the log-odds or logit of the probability of success (p).

$\beta_0, \beta_1, \beta_2, ..., \beta_p$ are the coefficients of the independent variables $X_1, X_2, ..., X_p$.

$X_1, X_2, ..., X_p$ are the independent variables or predictors (Gupta & Kapoor, 2009).

The logistic regression model uses maximum likelihood estimation to estimate the coefficients β0, β1, β2, ..., βn that best fit the observed data. Once the coefficients are estimated, they can be used to predict the probability of the binary outcome for new observations.

To make predictions, the logistic function (also called the sigmoid function) is applied to the linear combination of the predictor variables:

$$P = \frac{1}{(1 + e\char`^(-logit(p)))}$$

Where, e is the base of the natural logarithm.

In summary, binomial logistic regression is a useful model for predicting the probability of a binary outcome based on predictor variables. It allows us to understand the relationship between the predictors and the outcome, and it provides a way to make predictions for new observations.

3.2.2 Machine Learning Algorithm

Creating a village-wise probability of Foot and Mouth Disease (FMD) risk map in Karnataka using machine learning involves several key steps, from data collection and preprocessing to model selection, training, and spatial mapping.

Data Collection and Preprocessing

- Disease Incidence Data: Collect historical FMD case data at the village level, including the number of outbreaks, dates, and affected livestock populations. Georeferencing of the village level FMD data was performed.
- Environmental Data: Gather environmental data such as land use/land cover (from remote sensing), vegetation indices (e.g., NDVI), elevation, temperature, humidity, and precipitation. These variables can influence FMD transmission and should be collected at the highest spatial resolution possible.
- Machine learning (ML) methods such as neural networks and support vector machines have been developed for modelling disease data. These methods are less

frequently used in ecology or epidemiology due to the difficulty of biological interpretation. We used machine learning algorithm for developing risk map for FMD in Karnataka. The machine learning algorithm was performed in R (Goldstein *et al.,* 2017; Kuhle *et al.,* 2018)

3.3 Results

The outbreak map for villages in Karnataka from May 2020 to Dec 2021 was done. Map of the outbreaks are more concentrated in southern region of Karnataka compare to northern region during the study period (Figure 3.1). In Karnataka, during the period from May 2020 to December 2021, 234 outbreaks of FMD were reported. The buffalo population, cattle population, and land surface temperature were identified as important risk factors for spatial risk of FMD in Karnataka. The risk map developed was showed high risk of the disease in southern region of Karnataka. The risk map of Karnataka state were depicted in (Figure 3.3.1). Found there are three significant variables influencing the occurrence of FMD. (Figure 3.3.2) shows the response curve for the significant variables. The risk of disease increases with an increase in the cattle population. For Minimum and Maximum night-time, LST is showing an increasing trend, and after that, it starts decreasing. It means that a certain range of temperature that is influencing the occurrence of the disease (temperature is in degree celicus).

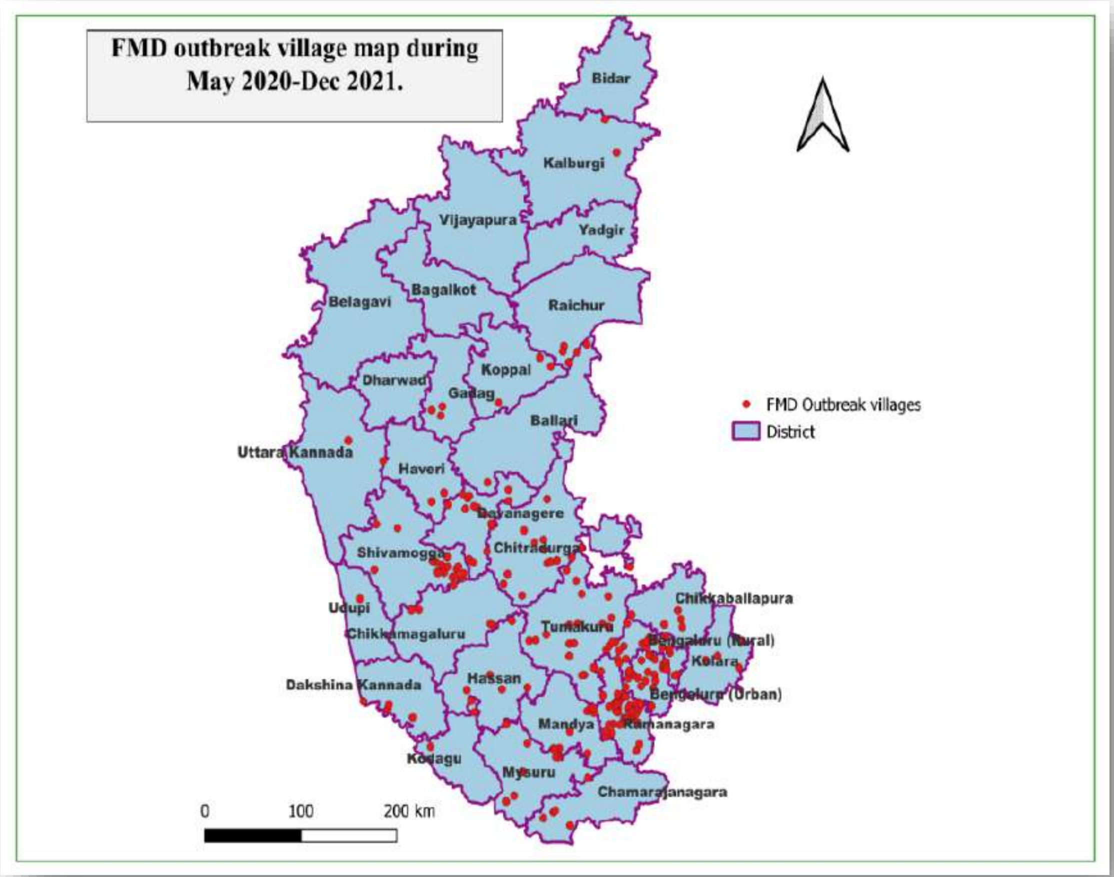

Figure 3.3.1 *Village-wise FMD outbreak map from May 2020 to Dec 2021.*

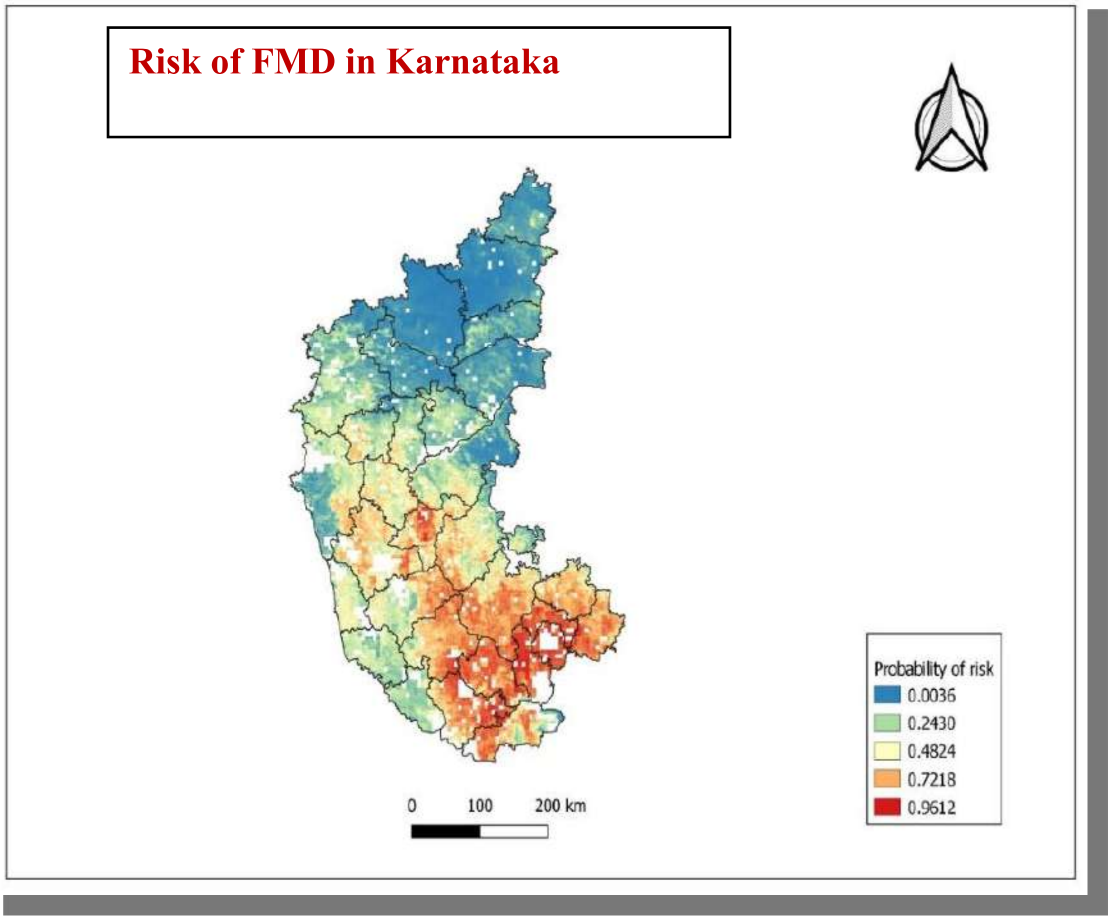

Figure 3.3.2 *Village wise probability of FMD risk map of Karnataka.*

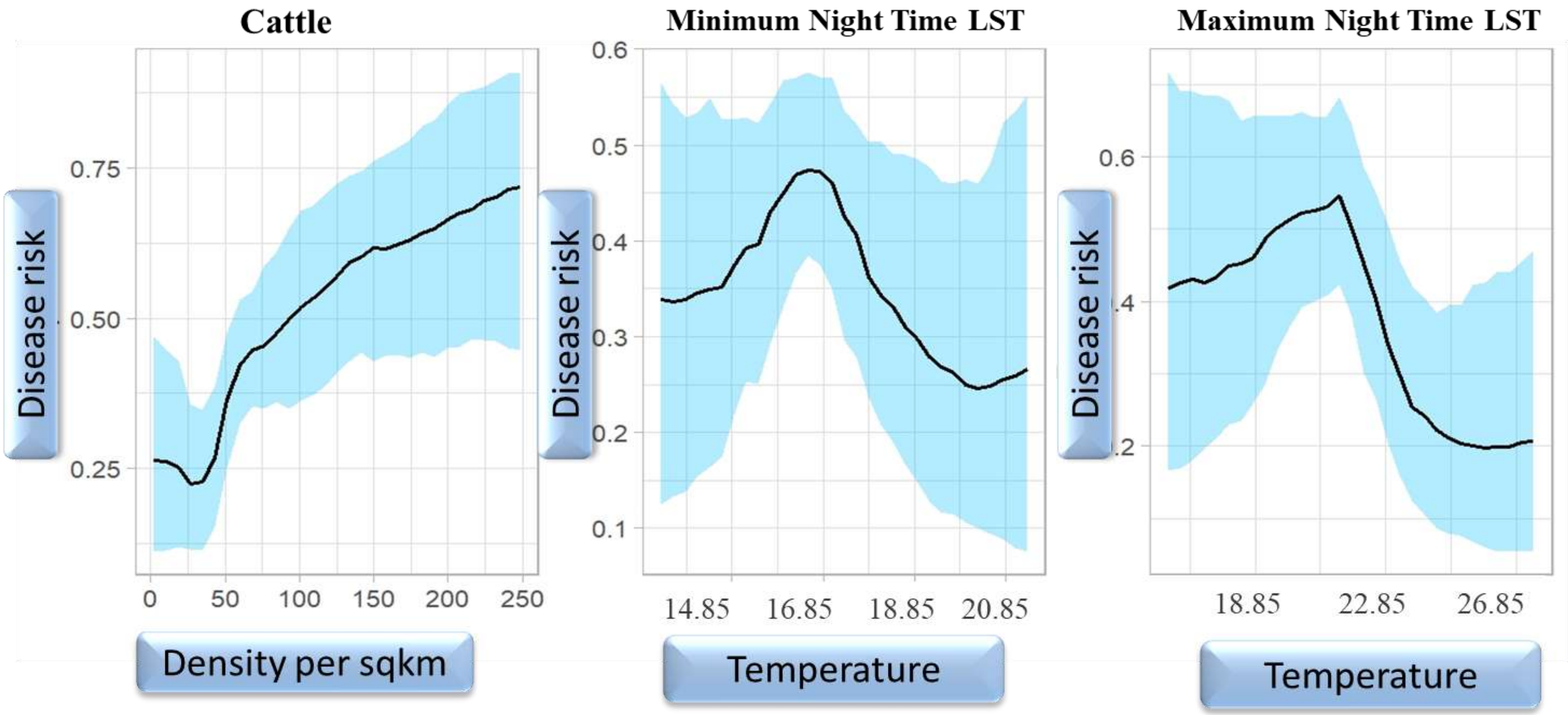

Figure 3.3 3 *Response curves of important variables which are influencing on occurrence of FMD*

3.4 Discussion

In our study, the village level FMD data was used and georeferencing was done to match the exact village name with website by using latitude and longitude co-ordinates. It is very useful to increase the accuracy of the villages where the FMD outbreaks were occurred in Karnataka that can be used to develop risk map. A similar study was conducted in south Africa to find the risk areas by using the georeferenced locations (Sirdar *et al.,* 2021). The user friendly online Georeferencing tool, was used for the covid-19 disease surveillance activity(Arias-Carrasco *et al.,* 2021). Binomial logistic regression models were used to find the potential risk factors for the occurrence of FMD outbreaks at village level in Karnataka, because the data was binary in nature and Binomial logistic regression was designed to handle binary outcomes, making it an appropriate choice for modeling disease risk.

Similar studies, includes that the spatially identified the high-risk areas in South Africa. Eleven risk factors were identified by using the multivariable conditional logistic regression model. Using the probabilities maps were developed by using the smoothed Bayesian kriging (Sirdar *et al.,* 2021). There are some important methods used for risk mapping are mentioned, Kriging is the one which is a regression method that provides a least square estimate of the data. A strength of this type of interpolation is that it not only produces an interpolated spatial model, but also an estimate of the uncertainty of each point in that model (Remy *et al.,* 2009). The probability of Co-Kriging model was used to assess the spatial distribution of FMD outbreaks during 1996 to 2000(Perez *et al.,* 2006). GIS was used for identifying the geographical location and distribution of various diseases (Ali & Ahmad, 2018, 2020). A risk map was developed using the significant risk factors using GIS and Machine Learning. GIS techniques used to analyze and visualize the spatial distribution of FMD risk areas integrated with livestock density, wildlife distribution, vaccination coverage, and historical outbreak data South Africa (R. C. Krebsbach, 2014). GIS-based multi-criteria evaluation approach to conduct a spatial risk analysis of FMD in Turkey associated with factors, livestock density, transportation routes, animal markets, and environmental variables to assess the risk of FMD occurrence across different regions (Yildirim, 2019). The study conducted in Uganda and used GIS techniques and incorporated factors such as livestock density, proximity to water bodies, and road networks to assess the spatial distribution of FMD risk (Dione *et al.,* 2017). A GIS-based technique was used in China to produce a map showing the hotspots, directional trend, and spreading pattern for every outbreak (Chen *et al.,* 2020). The risk mapping of FMD in Mainland Southeast Asia. The authors employed GIS techniques and integrated various factors such as livestock density, land use, transportation routes, and vaccination coverage to assess the spatial distribution of FMD risk. The study provides insights into the high-risk areas for FMD in Mainland Southeast Asia, enabling the development of targeted control and prevention measures in the region (Bounmany *et al.,* 2019). In India also, GIS technique and integrated factors like livestock density, Trade routes and Vaccination coverage used to assess the spatial distribution of FMD (Balamurugan *et al.,* 2014). The methods for assessing risk of disease range from disease modelling to visualization (Carroll *et al.,* 2014). A weighted linear combination followed by disease mapping is a typical technique for risk estimation using quantitative data, published literature, or expert opinion, The risk mapping will help for developing the policies for risk management and strategies (Pfeiffer *et al.,* 2008). The geographic patterns and finally understand the epidemiology of disease spread, can be described using spatial analysis of FMD data. Furthermore, risk mapping can be used to depict the transmission of epidemic diseases, including their introduction and local or long-distance spread. Finding places with a high risk of virus introduction or transmission is made easier with the help of this analytical technique (Premashthira *et al.,* 2011). The spatial risk assessment of FMD in India using GIS and multi-criteria decision analysis was done and integrated factors such as livestock density, trade routes, and environmental variables to assess the spatial distribution of FMD risk. The author aims to provide a comprehensive understanding of FMD risk across India (Manoj Kumar *et al.,* 2017). GIS techniques used to identify the spatial clusters and hotspots of FMD in Karnataka state (Gupta, 2020). Climate played an important role in FMD spatial epidemiology (Rahman *et al.,* 2020). FMD was found to be more common during the dry season, and where human and livestock movements were the predominant (Ayebazibwe *et al.,* 2010). Higher beef cattle density, higher pig density, and increased distance to wildlife protected areas were all shown to be positively associated with the risk of FMD (Chimera *et al.,* 2022). The spatial risk assessment and analysis of FMD in Karnataka state, India. The authors employed GIS techniques and integrated factors such as livestock density, road networks, and environmental variables to assess the spatial distribution of FMD risk. The research aims to provide insights into the high-risk areas for FMD in Karnataka state, assisting in the development of targeted control and prevention measures (Nagaraj *et al.,* 2020). The epidemiology of FMD outbreaks in Karnataka from 2008 to 2012.The authors analyzed the temporal distribution of FMD cases, identified the affected districts, and examined the disease patterns (Narayanan *et al.,* 2014). In figure 3.3 showed that the response curves of the important variables which are influencing on the occurrence of FMD.

3.5 Conclusion

Spatial risk maps of FMD serve as valuable tools for policymakers, veterinary authorities, and other stakeholders to focus on intensive surveillance involved in disease control and prevention and plan for systematic vaccination in high-risk areas to reduce the burden of the disease to rural farmers and achieve the targets of FMD control program. They can assist in targeting surveillance efforts, optimizing resource allocation, and implementing preventive measures in areas identified as high-risk zones, thereby supporting proactive management and containment of FMD outbreaks.

3.6 References

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Chapter 4

Identification of Managemental Risk Factors for Occurrence of FMD in Karnataka Using Statistical Methods.

4.1 Introduction

Animals with cloven feet, such as cattle, buffalo, sheep, goats, pigs, water buffalo, and other domestic and wild species, are susceptible to the highly contagious viral disease known as foot and mouth disease (FMD) (OIE, 2012). It is complicated to stop the transmission of the virus from infected livestock to susceptible livestock and the documentation of windborne transmission of the outbreak took place in 2007 (Schley *et al.,* 2009). Foot and mouth disease virus can be spread directly through aerosols and indirectly through mechanical transmission through insects and animal products like milk, meat, semen, or embryos (Sharma *et al.,* 2015). The virus can remain in the soil for three days in summer and up to 28 days in winter (Hugh-Jones & Wright, 1970). Some researchers well documented that the seasonal rise in FMD outbreaks leads to an epidemic status in different countries (Klein *et al.,* 2008). Food security and national economies are seriously threatened by the disease, which is highly contagious and can traverse domestically and internationally (Jamal *et al.,* 2011; Rweyemamu *et al.,* 2008). An estimated Rs. 200 billion in direct economic losses were attributed to FMD in India (Venkataramanan *et al.,* 2006). The annual loss on average per cattle and buffalo in India is estimated to be Rs. 125, but this does not include the production figure and animal drought power losses (Saxena, 1994). The FMD control program biannually vaccinates all cattle and buffaloes in selected areas, followed by regular active surveillance and antibody monitoring in the vaccinated population (Pattnaik *et al.,* 2012). It has been proven that serotypes O, A, and Asia 1 cause FMD outbreaks. Due to the diversity of circulating viral strains, unrestricted animal mobility, and asymptomatic or subclinical infection of primarily small ruminants, the disease situation in India is difficult. FMD control program (FMD-CP) is being implemented to create FMD-free zones in India. The livestock density positively correlates with the number of cases and disease incidence (Khounsy *et al.,* 2008; Verma *et al.,* 2010). Every year in India, there are outbreaks of FMD happening in Karnataka. It is very important to know the management risk factors that are influencing the occurrence of the disease. The present study aimed to identify the influence of household-level risk factors on the occurrence of Foot and Mouth Disease in Karnataka.

4.1.1 Risk factors

The FMD is endemic in India, due to different factors which are helpful for the occurrence of the disease which includes climatic factors (temperature, rainfall, humidity) Non-climatic factors (Animal type, breed, sex) and managemental factors (Movement of animal, Grazing pattern, animal density). Several risk factors are responsible for the occurrence of FMD have been studied by researchers in different countries around the world.

4.1.1.1 Climatic Different risk factors influencing the occurrence of FMD

According to (Kakker & Sharma, 2003), aerosol dispersal is influenced by wind speed and is aided by low temperatures, high levels of humidity, and cloud cover. The air-borne spread has primarily been observed in temperate settings with high levels of humidity (60%) and dense populations of animals.

4.1.1.2 Non-climatic Risk factors influencing the occurrence of FMD

Age, contact history with wild animals, distance from parks and wildlife sanctuaries, and herds' movement pattern were significant risk factors for FMD in Southwestern Ethiopia (Molla *et al.,* 2010). From the main risk factors investigated, it was found that age categories of animals, agricultural methods, sex, breed, and seasonal influence had a significant relationship with the prevalence of FMD in Rajshahi (Sarker *et al.,* 2011). In Afghanistan, a study was conducted to know the risk factors through the Spatiotemporal method and found the prevalence of Foot & Mouth Disease in females was higher than in males. The study was conducted in Iraq to find the important risk factors, including Animal age (>6 months -2 year), females, pregnant animals, herd size non-vaccinated, and imported animals (Salim *et al.,* 2020). According to an analysis by Perez *et al.,* (2004) from Argentina, 94% of outbreaks were situated in the Pumpeana region, where the cattle population was concentrated, and the outbreaks were clustered and strongly ($P<0.01$) linked with herd density.

4.1.1.3 Managemental risk factors influencing on occurrence of FMD

The study conducted in the Cameroon region of Adamawa state noticed purchasing cattle from markets, mixing herds at watering locations, feeding cotton-seed cake, feeding buffalo nearby the herd, and administrative division were risk factors for FMD (Bronsvoort *et al.,* 2004). Research findings indicate that rather than transnational movements or contact with animals, FMD incidence in Tanzania is more closely associated with animal mobility and human activities through communication networks (Allepuz *et al.,* 2015). Risk factors for cattle and pig farms were separately identified in Japan. In Cattle, farms are mainly associated with the farm equipment shared with other farms visit of feed transportation vehicles and visit of livestock-related staff to the farm but in case of Pigs, farms' risk factors were fattening farm and physical barriers in the barn (Muroga *et al.*, 2013b). Based on the earlier disease situation a study was conducted in Sri Lanka, the researcher used a logistic regression model to know the potential risk factors associated with FMD spread. Cattle and buffalo interactions with nearby villages, grazing near water tank areas, during the outbreak, animals bought or sold, being near to a road where animal traders travel and being fed on the floor were important risk factors (Gunasekera *et al.*, 2017). FMD-infected farms and FMD-free farms comparison study was conducted in Iran to find the risk factors using multivariable logistic regression models and found FMD infection is more likely in farms with poor hygienic conditions, low vaccination rates, livestock transportation problems, and inhibition of livestock dealers' entry into the farm and risk-based strategy plan was taken based on the risk- factors and FMD control based on progressive control Pathway (Ilbeigi *et al.*, 2018). Household-level risk factors were identified in the Greater Mekong subregion and found practice of new animal quarantine for two weeks before introducing a herd, communal grazing land sharing is beneficial (Miller *et al.*, 2018). A study was conducted in Thailand, and the researcher identified the risk factors at the farm level for FMD outbreaks and it were ; purchasing of a new cow without following quarantine protocol, farms located near shared cattle grazing areas, FMD vaccination administration by non-official livestock personnel, and no history of FMD outbreaks over the previous 12 months in districts where farms were located and recommended the biosecurity measures for disease control (Sansamur *et al.*, 2020). The study was conducted in Pakistan and said that disease control by educating the farmers, mass vaccination and animal movement restriction are very important risk factors (Ali *et al.,* 2022). Animal movement rules should be taken into consideration for the long-term control of FMD because uncontrolled and regular animal movements are the likely reasons for high outbreak occurrence during the dry season in Uganda (Okello *et al.,* 2022). Animal movements, farms with livestock and crops, large and medium farms as compared with small farms, and geographic location were associated with disease infection in Uruguay. There was a significant risk of FMDV infection associated with keeping cattle only during the subsequent epidemic period, and this risk persisted throughout the epidemic. Dairy farms had a higher probability of FMDV infection than beef farms (Iriarte *et al.,* 2023). A cross-sectional study was conducted to identify the important risk factors in Uttar Pradesh India and identified the sex of the animal mainly associated with FMD seropositivity and female animals are at high risk compare to male animals (Afroz *et al.,* 2023). Decision tree-risk analysis was done in Egypt for the prevention of FMD outbreaks. It was identified that physical evaluation of recently purchased animals before arrival, mixing with a premises beef herd, followed by immunisation against FMD (ElAshmawy *et al.*, 2023). A recent study showed that the main challenges to managing and preventing FMD in the region include insufficient quarantine restrictions, a lack of routine immunization, and unrestricted animal movement (Bayantassova *et al.,* 2023).

4.2 Material and Methods

4.2.1 Study area

Karnataka is the seventh largest state which covers an area of 1,91,791 square kilometres. The total livestock population in Bangalore-rural, Chikkamagaluru, Davangere, and Shivamogga districts is 2.4 million of which Cattle 1.2 million, and buffalo population is 0.26 million (Department of Animal Husbandry, Dairying & Fisheries (DAHD&F), Government of India, 2019). Based on the list of the FMD-affected villages collected from the Department of Animal Husbandry and Veterinary Services for the period from September 2021 to December 2021, randomly selected four villages from four different districts of Karnataka state. The geographical location of the study area is presented in (Figure 4.2.1).

4.2.2 Data collection

A semi-structured questionnaire was developed to identify household level management risk factor influencing the occurrence of FMD. The questionnaire's first set of sections were on basic information concerning livestock details, including farmer names, animal numbers, disease information, and vaccination information. In next section questions were related to source of fodder, source of water, contact tracing, including the purchase of new animals, migratory flocks in the village, and middlemen's involvement in buying and selling the animals. The last section was about animal housing and rearing practices, including the housing system, animals being closely tied/sheltered under one roof, disinfectant usage, ventilation in animal sheds, the shed close to continuously flooded swamps, previous history of FMD cases, number of animals affected or suspected for FMD in the surrounding locality, etc. Data were collected through personal interviews with 432 household farmers.

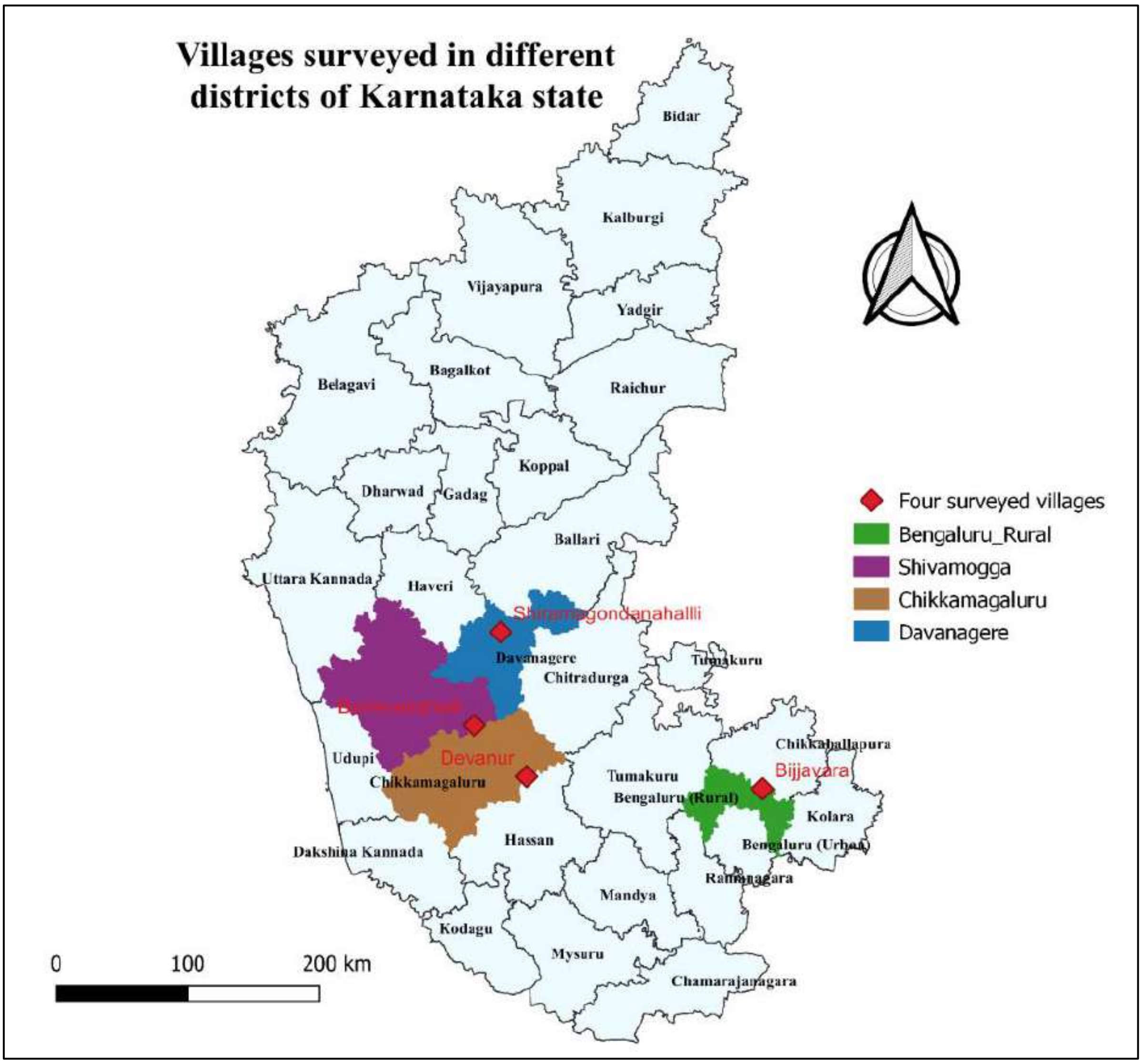

Figure 4.2.1 *Map showing survey conducted villages in different districts of Karnataka.*

4.2.3 Statistical Analysis

Statistical analysis was performed using the SPSS software version 25.0 to find important predictor variables associated with the FMD outbreaks in four villages of four districts of Karnataka state, based on the R^2 value. Important risk factors were identified and then used as essential risk factors to build the binomial logistic regression model.

4.2.3.1 Binomial Logistic Regression

A multivariate regression relationship was built using logistic regression analysis between one dependent variable and multiple independent variables. Quantitatively, the relationship between the event and its dependence on various variables was expressed as follows:

$$\boldsymbol{P = \frac{1}{(1+e^{-z})}}$$

Where p is the probability that an event will occur, the value of p ranges from 0 to 1 on the s-shaped curve, and z is the linear combination. It follows that logistic regression consists of fitting an equation of the following form to the data:

$$\boldsymbol{Z = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_n x_n}$$

Where, b_0 is the intercept of the model, bi (i=0, 1, 2,…,n) are the slope coefficients of the logistic regression model, and x_i (i=0, 1, 2,…,n) are the independent variables. Using the binomial logistic regression model, the managemental risk factors that mainly influence the occurrence of FMD were assessed.

4.2.3.2 Potential biases in the study

When conducting a primary survey to collect household-level managemental risk factors, several potential biases and limitations can arise. If the sample is not representative of the population, the results may not generalize to the entire population. This can occur due to non-random sampling methods or an incomplete sampling frame.

- If certain households are more likely to be included in the survey due to their location, socioeconomic status, or willingness to participate, this could skew the results.

- Respondents may answer questions in a manner they believe is socially acceptable or desirable rather than providing truthful responses, particularly on sensitive topics such as hygiene practices or financial status.
- If respondents are asked to recall past events or behaviours, they may not remember accurately, leading to misreporting.
- If the survey questions are phrased in a way that suggests a particular answer, this can influence responses and lead to biased results.
- If the questions are too complex or use technical language, respondents may misunderstand them, leading to inaccurate answers.
- A long survey can lead to respondent fatigue, where respondents provide less thoughtful answers as the survey progresses, potentially leading to incomplete or less accurate data.
- The presence or behaviour of the interviewer may influence how respondents answer questions. For example, if an interviewer unintentionally signals approval or disapproval of certain responses, it could affect the respondent's answers.
- If different interviewers administer the survey differently, it can lead to variability in the data collected.
- Mistakes in data entry or coding can introduce errors into the dataset.
- The choice of analytical methods or models may introduce bias if not appropriately selected or if assumptions are violated.
- If respondents fear that their information might not be kept confidential, they might withhold or alter their responses.
- If the survey focuses only on specific regions, demographics, or household types, the findings may not be generalizable to other contexts.

Addressing these potential biases and limitations requires careful survey design, rigorous sampling methods, thorough training of interviewers, and thoughtful data analysis techniques. Pre-testing the survey and conducting pilot studies can also help identify and mitigate some of these issues before the full survey is conducted. In our study, we used a statistically significant sample size for the survey. Pilot testing of questionnaires was performed. Efforts were made to limit the above-mentioned biases.

4.3 Results

In our study, data from each village was tabulated, and the percentage for each parameter was calculated as per the questionnaire. General information on the percentage of all four villages' data is presented in Table 4.3.1. The results show that out of 432 households surveyed, 61 households reported FMD during the period (Sep 2021 to Dec 2021) in 4 villages of 4 different districts in Karnataka state.

The Bommenahalli village of Shivamoga district reported more affected households [n=20, (29.4%)], next Devanur village of Chikkamagalore district has [n=19, 13.1%)], Bijjavara village of Bangalore rural has [n=13, (16.7%)], and Shiramagondanahalli village of Davangere district has [n=9, (11.3%)], not affected households were more in Shiramagondanahalli [n=80, (89.9%)] and less in bommenahalli [n=68, (77.3%)] (Table 4.3.1). The village-wise cumulative affected and not-affected households in the bar diagram show that Bommenahalli village has the maximum number of affected households and Shiramagondanahalli has the least number of affected households, as shown in (Figure 4.3.1). In the present study, a binomial logistic regression model was fitted for the FMD occurrence related to managemental risk factors. The validation results show that the binomial logistic regression model has a prediction accuracy of 95 %. Found that the presence of middlemen in the buying and selling of animals ($P<0.01$), animals that are closely tied together ($P<0.01$), source of water for livestock ($P<0.01$), history of FMD ($P<0.01$), and source of Water ($P< 0.01$) were significant risk factors for the occurrence of FMD in the villages surveyed (Table 4.3.3). The protection factors discussed in (table 4.3.4). Each play a protective role against the spread of FMD when managed effectively. Here's a summary of these protective factors. Grazing and combination feeding (both) are more likely to increase the risk of FMD transmission compared to strict stall-feeding, due to increased exposure to other animals and potentially contaminated grazing areas. Stall feeding tends to be safe in terms of FMD prevention as long as biosecurity measures are maintained for feed and equipment. Pond water is more likely to increase the risk of FMD compared to tap water, as it can be contaminated by infected animals. Using both also increases the risk, but the use of clean tap water is the best option for minimizing FMD transmission through water. Purchased animals are more likely to increase the risk of FMD transmission compared to not purchasing any new animals. Implementing a strict quarantine and health screening process for any newly purchased animals can help minimize this risk. The presence of migratory animals increases the risk of FMD transmission to domestic herds, as they can carry and spread the virus across regions. Keeping livestock in areas where contact with migratory animals is minimized helps reduce this risk. Open yards and temporary/kachha housing are more likely to increase the risk of FMD transmission compared to permanent/pakka housing, which allows for better biosecurity, cleaning, and containment. A well-maintained pakka housing system is generally the safest option to help prevent FMD spread. Closely tying animals can increase the risk of FMD spread within a herd if the virus is introduced. Keeping animals not closely tied and allowing more space between them can reduce this risk by limiting direct contact and aiding in biosecurity measures. Not using disinfectants increases the risk of FMD transmission, as the virus can survive on uncleaned surfaces and equipment. Regular use of disinfectants is an effective way to reduce FMD risk by eliminating viral particles from the environment. Poor ventilation or No increases the risk of FMD transmission due to the buildup of viral particles and higher humidity. Proper ventilation is preferable as it reduces this risk by improving air quality, lowering humidity, and dispersing potential contaminants.

Table 4.3.1 *Number of households surveyed in four districts and Percentages of affected and Not-affected household details of Karnataka.*

Village	Total number of households surveyed	Affected households number	Not-affected households number
Bijjavara	91(21.07)	13 (14.29)	78 (85.71)
Bommenahalli	88 (20.37)	20 (22.73)	68 (77.27)
Devanur	164 (37.96)	19 (11.59)	145 (88.41)
Shiramagondanahalli	89 (20.60)	9 (10.11)	80 (89.89)
Total	432 (100)	61 (14.12)	371 (85.88)

(*Figures in parentheses indicate the percentages of affected and non-affected households*).

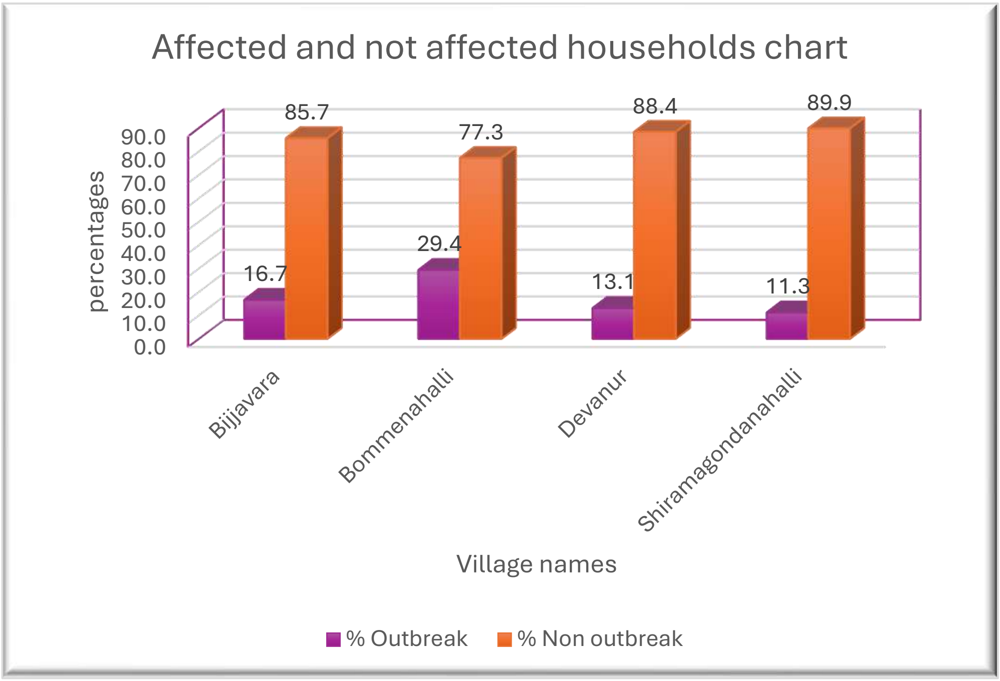

Figure 4.3.1 *Bar diagram for village-wise FMD affected and not-affected households from primary surveyed villages.*

Table 4.3.2 *General characteristics of livestock holding and management practices of sampled farmers in surveyed villages of four districts in Karnataka state.*

Village Names	**Devanur**		**Bommenahalli**		**Bijjavara**		**Shiramagon danahallli**	
Basic Information								
	No	%	No	%	No	%	No	%
Total number of Animals	603		268		274		441	
Total number of cattle	517	85.74	247	92.16	268	97.81	391	88.66
Total number of sheep	86	14.26	0	0.00	0	0.00	50	12.79
Total Number of Buffalo	0	0	21	7.84	6	2.19	0	0.00
The number of Cattle affected	42	8.12	61	24.70	55	20.52	34	8.70

Awareness of Disease	164	100.0	88	100.0	91	100.0	89	100.0
Status of Vaccination	164	100.0	88	100.0	91	100.0	89	100.0
Source of Fodder								
Grazing	1	0.61	26	29.55	11	12.09	26	29.21
Stallfeeding	12	7.32	24	27.27	39	42.86	25	28.09
Both	151	92.07	38	43.18	41	45.05	38	42.70
Source of Water								
Tap water	13	7.93	26	29.55	91	100.0	26	29.21
Pond water	3	1.83	0	0.00	0	0.00	0	0.00
Both	148	90.24	62	70.45	0	0.00	63	70.79
Contact Tracing								
Animals purchase								
Not purchased	102	62.20	84	95.45	88	96.70	83	93.26
Purchased	62	37.80	4	4.55	3	3.30	6	6.74
Migratory animals								
Not Present	164	100.0	88	100.0	91	100.0	89	100.0
Present	0	0.00	0	0.00	0	0.00	0	0.00
Middle man involvement								
Not involved	146	89.02	86	97.73	91	100.0	87	97.75
Involved	18	10.98	2	2.27	0	0.00	2	2.25
Animal housing and rearing practices								
Housing system								
Temporary/ Kachha	102	62.20	0	0.00	9	9.89	4	4.49
Permanent/Pakka	62	37.80	85	96.59	81	89.01	76	85.39
Open Yard	0	0.00	3	3.41	1	1.10	9	10.11
Animals closely tied								
No	164	100.0	7	7.95	0	0.00	7	7.87
Yes	0	0.00	81	92.05	91	100.0	82	92.13
Disinfectant use								

No	160	97.56	79	89.77	88	96.70	80	89.89
Yes	4	2.44	9	10.23	3	3.30	9	10.11
Proper ventilation in the shed								
No	0	0.00	11	12.50	0	0.00	12	13.48
Yes	164	100.0	77	87.50	91	100.0	77	86.52
Source of water for livestock								
Rivers/Stream/channels	0	0.00	10	11.36	0	0.00	10	11.24
Tanks/ ponds	0	0.00	19	21.59	0	0.00	19	21.35
Municipality taps	6	3.66	45	51.14	0	0.00	45	50.56
Bore wells	158	96.34	14	15.91	91	100.0	15	16.85
Others	0	0.00	0	0.00	0	0.00	0	0.00
History of FMD								
No	0	0.00	84	95.45	85	93.41	89	100.0
Yes	164	100.0	4	4.55	6	6.59	0	0.00

the number of responses in each village depicted and the percentage of responses in all four surveyed villages.

Table 4.3.3 *Estimated values coefficients of binomial logistic regression model for FMD.*

Parameter	Estimate value	Standard error (95% CI)
(Intercept) ***	1.175	0.120 (0.938, 1.411)
Presence of middlemen in buying and selling of animals ***	0.668	0.067 (0.536, 0.800)
Animals that are closely tied under one roof ***	-0.310	0.076 (-0.459, -0.161)
Source of water for livestock ***	-0.180	0.022 (-0.224, -0.135)
History of FMD ***	0.220	0.43 (0.136, 0.304)
Source of Water ***	-0.103	0.020 (-0.142, -0.063)

Significant at 10%, * *Significant at 5%, * significant at 1%.*

Table 4.3.4 *Protection factors of livestock holding and management practices of sampled farmers in surveyed villages of four districts in Karnataka state.*

Village Names	Devanur	Bommenahalli	Bijjavara	Shiramagondanahalli
	Number (%)	Number (%)	Number (%)	Number (%)
Source of Fodder				
Grazing	1 (0.61)	26 (29.55)	11 (12.09)	26 (29.21)
Stallfeeding	12 (7.32)	24 (27.27)	39 (42.86)	25 (28.09)
Both	151 (92.07)	38 (43.18)	41 (45.05)	38 (42.70)
Source of Water				
Tap water	13 (7.93)	26 (29.55)	91 (100.0)	26 (29.21)
Pond water	3 (1.83)	0 (0.00)	0 (0.00)	0 (0.00)
Both	148 (90.24)	62 (70.45)	0 (0.00)	63 (70.79)
Animals purchase				
Not purchased	102 (62.20)	84 (95.45)	88 (96.70)	83 (93.26)
Purchased	62 (37.80)	4 (4.55)	3 (3.30)	6 (6.74)
Migratory animals				
Not Present	164 (100.0)	88 (100.0)	91 (100.0)	89 (100.0)
Present	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Housing system				
Temporary	102 (62.20)	0 (0.00)	9 (9.89)	4 (4.49)
Permanent	62 (37.80)	85 (96.59)	81 (89.01)	76 (85.39)
Open Yard	0 (0.00)	3 (3.41)	1 (1.10)	9 (10.11)
Animals closely tied				
No	164 (100.0)	7 (7.95)	0 (0.00)	7 (7.87)
Yes	0 (0.00)	81 (92.05)	91 (100.0)	82 (92.13)
Disinfectant use				
No	160 (97.56)	79 (89.77)	88 (96.70)	80 (89.89)
Yes	4 (2.44)	9 (10.23)	3 (3.30)	9 (10.11)
Proper ventilation in the shed				
No	0 (0.00)	11 (12.50)	0 (0.00)	12 (13.48)
Yes	164 (100.0)	77 (87.50)	91 (100.0)	77 (86.52)

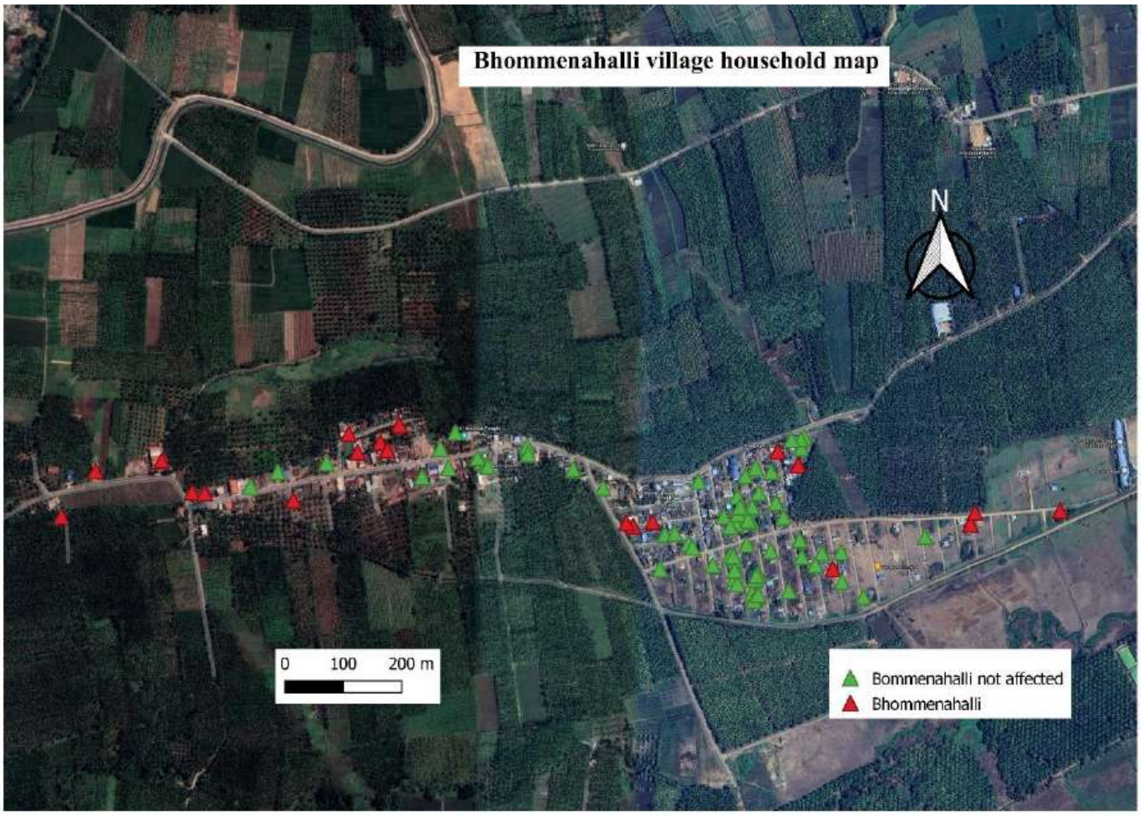

Figure 4.3.2 *Bommenahalli village maps showing affected and not-affected households*

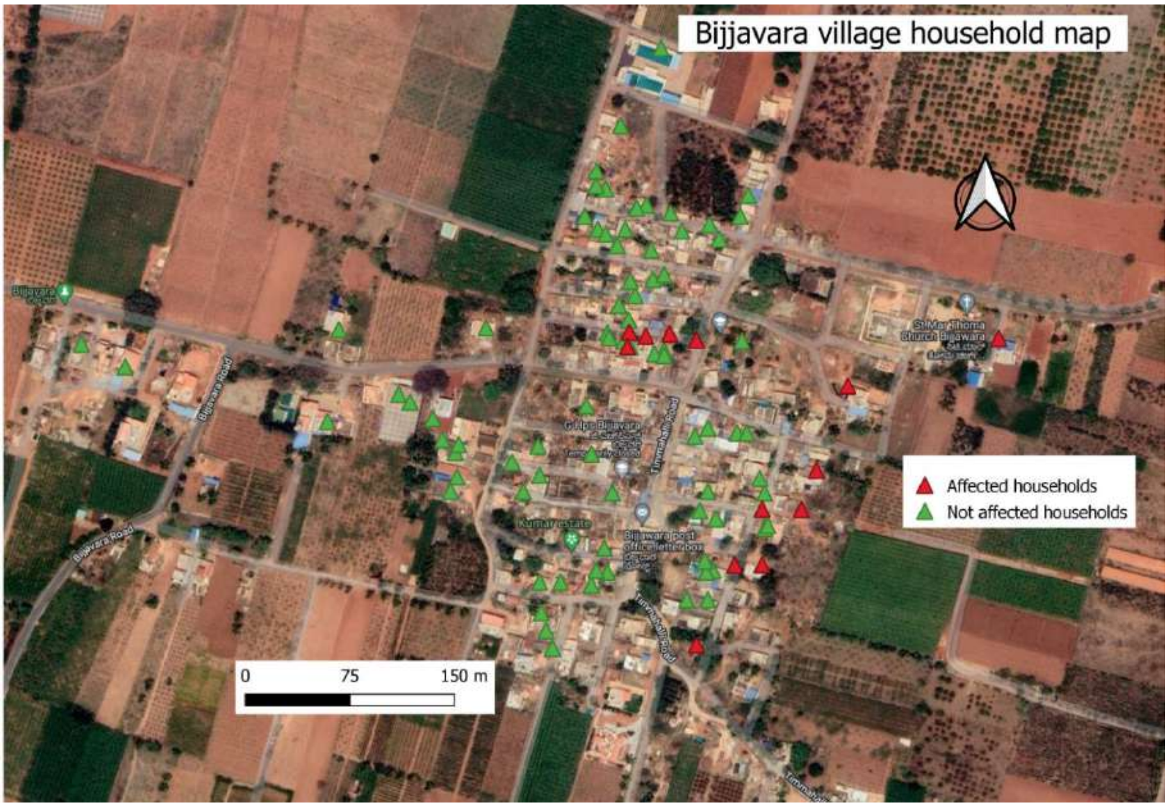

Figure 4.3.3 *Bijjavara village maps showing affected and not-affected households*

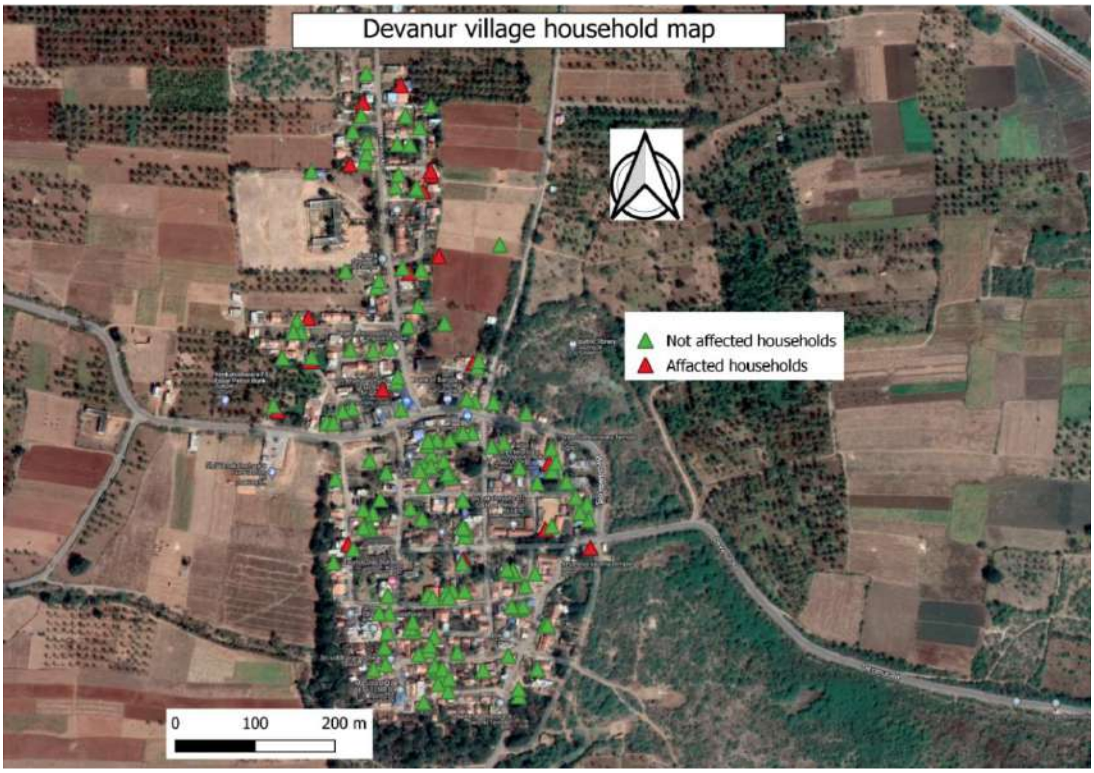

Figure 4.3.4 *Devanur village maps showing affected and not-affected households*

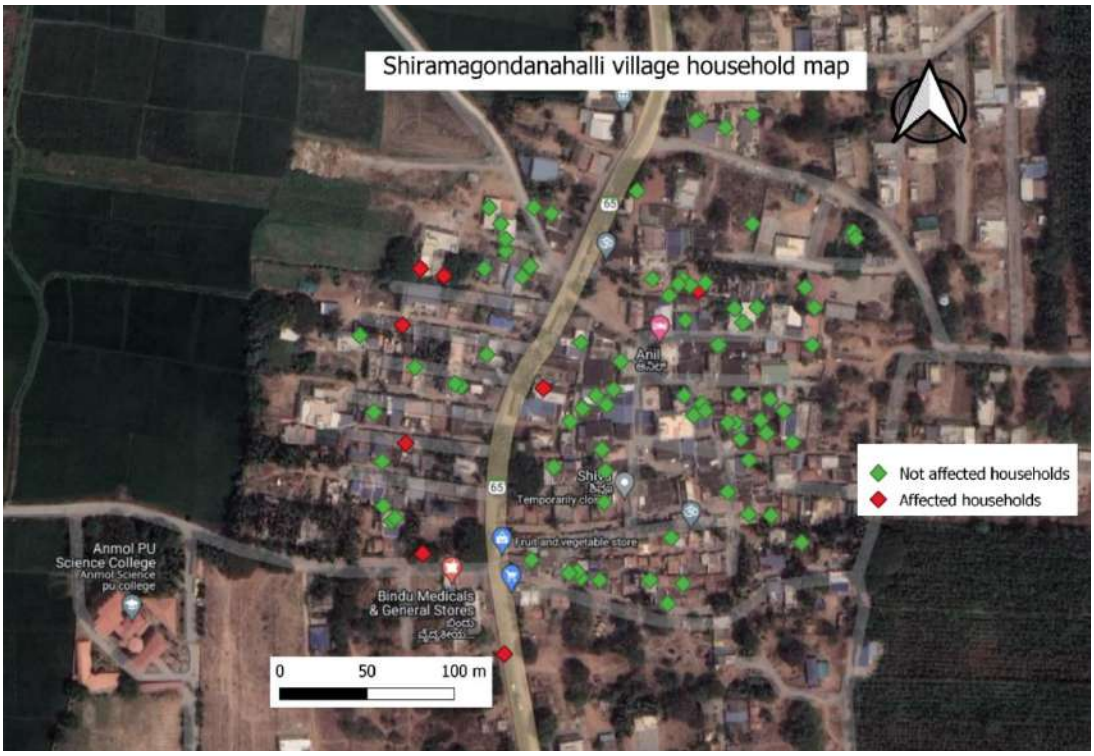

Figure 4.3.5 *Shiramagondanahalli village maps showing affected and not-affected households*

4.4 Discussion

The study was based on the primary data collected through a semi-structured questionnaire survey. The questionnaire assessed the most important management risk factors associated with FMD. The questionnaire was used to assess the most important management risk factors associated with the occurrence of FMD and also know the epidemiology and spread of the virus in particular villages of Karnataka state. Similar studies were conducted in different countries to investigate the risk factors associated with FMD. In Punjab, Pakistan researcher used a standardised questionnaire was used to gather information from each farm on several factors (Ali *et al.,* 2022). (Udahemuka *et al.,* 2020) also used the questionnaire for the survey to know the risk factors for FMD outbreaks in Eastern Rwanda. A study conducted in Cameroon using a questionnaire and collected the annual migration aspects like types of grazing, feeding, watering, number of contacts between herds, other livestock kept and contact with wildlife and breeding information of the animal (Bronsvoort *et al.,* 2004). Vaccination information, age, mixed farming like keeping the cattle with small ruminants data was collected using the questionnaire (Megersa *et al.,* 2009) and the livestock management practises and prevalence of FMD in their herds using a standardised questionnaire by (Dukpa *et al.,* 2011). A primary survey was conducted in 127 farms having 46 FMD-infected farms and 81 FMD-free farms using a questionnaire (Ilbeigi *et al.,* 2018). (Ayebazibwe *et al.,* 2010), conducted a study during 2001-2008 to find the risk factors associated with occurrence of FMD outbreaks using the questionnaire in Uganda. (Udahemuka *et al.,* 2020) study identified and mapped the risk factors which are influencing the spread of FMD using the questionnaire survey data. In our study, found that middlemen (animal brokers) in buying and selling animals, a history of the disease, water source, ventilation condition in the animal house, and closely tied animals mainly influenced the occurrence of FMD. Presence of middle men (animal broker) in buying and selling of animal is the most significant factor in our study because in a survey conducted village the first case of was identified in the animal broker house, after that the disease spread to other households. Animals that are closely tied under one roof was identified as significant. It was also noticed that the history of FMD also plays a major role in occurrence of disease, because the animals are susceptible but not showing symptoms again may be important in recurrent FMD outbreaks. Ventilation inside the animal house also identified as significant in our study along with source of water. Similar studies conducted in different parts of the world are discussed. (Ali *et al.,* 2022), investigated the risk factors which were associated with the FMD outbreaks in the Panjab area from Jan- April 2019 and outbreak investigation was carried out in nine districts of Punjab and it was found that animal broker visit, distance between the livestock farms, FMD vaccination status, not practising regular vaccination against FMD and large size herd are the main risk factors responsible occurrence of FMD and concluded that taking biosecurity measures and new animal introduction without vaccination history. (Ilbeigi *et al.,* 2018), aimed to study the risk factors in the Khorasan Razavi area of Iran for the recurrence of disease using time series FMD outbreak data during 2012-2014 and found the important risk factors at farm level FMD infection. It was found that farm hygienic condition, status of FMD vaccination, livestock transportation and livestock dealers' entry into the farm as risk factors for the recurrence of FMD outbreak. (Ilbeigi *et al.,* 2018) also found several risk factors which includes buying cattle from markets, mixing of animal herds at watering points, feeding cotton-seed cake, buffalo near the herd and administrative division. (Ayebazibwe *et al.,* 2010), results showed that dry season months and the movement of animals are associated with the occurrence of FMD and they concluded that animal movement was the main risk factor for FMD outbreaks. (Udahemuka *et al.,* 2020) Identified risk areas to support the government control programme in Eastern Rwanda, based on livestock owner information of the disease occurred in the dry season. Univariate analysis showed mixed farming and natural breeding method and unvaccinated young animals (< 12 months) were associated with the occurrence of FMD at farm level. (Chimera *et al.,* 2022) modelling study was conducted using the retrospective data to build the spatiotemporal distribution and risk factors associated with FMD in Malawi's southern and northern regions. It was found that the FMD outbreak were in areas of high beef cattle density, higher pig density and distance to wildlife protected areas were positively associated with FMD risk and areas with international borders and roads were associated with less risk. A similar study in the UK indicated that the main agents for the disease's spread between livestock farms were animal brokers and dealers (Ortiz-Pelaez *et al.,* 2006). The animal age, contact history with wild animals, distance from parks and wildlife sanctuaries, and herds' movement pattern were significant risk factors for FMD in Southwestern Ethiopia (Molla *et al.,* 2010). A study has discovered that visits from employees of businesses involved with cattle are positively related to FMD outbreaks (Muroga *et al.,* 2013). (Wajid *et al.,* 2020) also conducted study in Afghanistan and found sex of the animal previous FMD cases in herd, animal shed and farms where neighbouring farmers used to visit area are the main risk factors.(Sansamur *et al.,* 2020) conducted study in Northern Thailand and noticed that the purchasing of new animal without following any protocol, FMD vaccination by non- official persons, farms located within 5 km of slaughterhouses, farms located within a radius of 10 kilometers near ordinary livestock pastures and where there was no outbreak of foot and mouth disease in the previous year are the important risk factors. (Miller *et al.,* 2018) also identified that introduction of new animal and the communal grazing of the animals are the important risk factors. Logistic regression model was used to know the potential risk factors associated with FMD spread in Sri lanka and it was found that, cattle and buffalo interactions with nearby villages, grazing near water tank areas, during the outbreak, animals bought or sold, being near to a road where animal traders travel and being fed on the floor were significant(Gunasekera *et al.,* 2017). A recent study showed that the main challenges to managing and preventing FMD in the region include insufficient quarantine restrictions, a lack of routine immunization, and unrestricted animal movement (Bayantassova *et al.,* 2023). In Karnataka also, the middleman visits several farms and markets to buy and sell the livestock daily and might spread FMDV to the susceptible farms. There must be restriction of the middleman movement, the mixing of animals should be avoided while grazing and watering. In our study, used the Binomial Logistic Regression model because the outbreak data was binomial (presence or absence) in nature. Multivariable analysis method was used to know the major risk factors responsible for the occurrence of the disease (Ali *et al.,* 2022). (Udahemuka *et al.,* 2020) also used Univariable and multivariable analysis. (Ilbeigi *et al.,* 2018) used the multivariable logistic regression model to find the of risk factors. (Udahemuka *et al.,* 2020) descriptive statistical analysis and calculate odds ratio and QGIS was used to produce the thematic maps based on the proportion of FMD risk.

4.5 Conclusion

In this study, concluded that middlemen involved in selling and buying animals should be restricted to move between affected and unaffected villages/households. Animals affected with FMD should be segregated immediately and treated. Clean water should be provided to animals. Animals should be tied in a well-ventilated area, and mixing of animals at a common source of water can be avoided to prevent the spread of FMD in villages.

4.6 References

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Chapter 5.
Spatial Mapping of FMD Serotypes in Karnataka

5.1 Introduction

The highly infectious viral disease known as foot and mouth disease (FMD), which affects animals with cloven foot, has a considerable potential to cause huge economic loss. Seven serotypes of the FMD virus (FMDV) are present: O, A, C, SAT 1, SAT 2, SAT 3, and Asia 1 (Carrillo *et al.,* 2005). Clinically, it is difficult to differentiate between FMD and other vesicular diseases such as swine vesicular disease, vesicular stomatitis, vesicular exanthema, and infection with the Seneca Valley virus. Additionally, each suspected FMD patient needs to have a test diagnostic performed immediately (WOAH, 2022a).

5.1.1 Serotypes of Foot and Mouth disease virus in world, India and Karnataka.

5.1.1.1 Serotypes of FMD in the World

FMD occurred worldwide, including the Middle East and North Africa, especially in Europe. The different epidemiological situations the risk management are also different in the areas. In north Africa, the disease was controlled based on Quarantine and the mass vaccination of the animals and also to reduce the disease in future the common strategies were adopted (Aidaros, 2002). In developing countries, there is no proper vaccination and the disease virus remains exists in nature. Found that the serotypes O and A could be found in almost all areas except the southern part of Africa. Serotype Asia 1 was located in southeast, south, and west Asia, and the three serotypes of SAT were found in the African continent (Paton *et al.,* 2009). FMDV serotypes are distributed differently in different parts of the world. Six of the seven FMDV serotypes O, A, C, SAT-1, SAT-2, and SAT3 have been found to have occurred in Africa, whereas four have been found in Asia and Europe (O, A, C, and Asia 1) (Valarcher *et al.,* 2009).

5.1.1.2 Serotypes of FMD in India

The disease situation in India is complicated due to the plurality of the circulating virus strains in serotypes O, A and Asia 1, unrestricted movement of animals from infected areas and noticeable infection in small ruminants. Among the serotypes, type O is the most prevalent, accounting for 83–93% of the outbreaks, followed by Asia 1 (3–10%) and A (3–6.5%). Serotype C has not been reported in the country since 1995. As per the National FMD sero-surveillance study, the average prevalence of FMD infection in the bovine population based on anti-3AB NSP-ELISA was found to be 27.5%, whereas, in goats, sheep and pig the prevalence has been found to be 20, 15 and 2%, respectively (Mahapatra *et al.,* 2011). The study was conducted in west Bengal state during 1985-2002 and noticed 1082 FMD outbreaks, which were more prevalent including four serotypes O (67%), Asia1 (15%), A (14%) and C (4%) and no C serotype cases after 1996 not recorded (Bhattacharya *et al.,* 2005). In India study was conducted by the researcher in different parts of the country to know the major serotypes and found there were three serotypes that prevailed O caused 80% of outbreaks, Asia 1 and A are 12% and 8% of infections respectively (S Subramaniam *et al.,* 2013). FMD outbreak first appeared in Punjab, then spread to Sindh, NWFP Balochistan, AJK, and Northern Areas. The Sheikhupura district in Punjab had highest incidence (54%) and Chakwal district had the lowest (10%). Khanewal district recorded the highest incidence (33%) and lowest in Bahawal Nagar district (0.5%). Sanghar district in Sindh had the highest incidence (33.78%), and Ghotki district had lowest (12.09%). In terms of NWFP, Kohat district had the highest incidence (37.33%), and Swat district had lowest (19.35%). Haripur district recorded the highest importance (20.75%), while Manshera district recorded the lowest (9.4%). In Balochistan, the highest prevalence (70%) was recorded in Chagi district, and lowest (2.50%) was recorded in Gawader district. The highest incidence (3.55%) was recorded in Lasbella district, while lowest (0.5%) recorded in Turbat district. In Azad Jammu and Kashmir (AJK), the highest (30.65%) incidence was recorded in Mirpur district, and the lowest (6.64%) was recorded in Palandri district. The highest (12.77%) incidence was recorded in the Mirpur district, and the lowest (7.11%) in Rawal kot district (Anjum *et al.,* 2004). To formulate the FMD control programme strategy in the Uttar Pradesh state of India. Because in the state during 2002-2006, 270 FMD outbreaks were reported, out of which 131 were confirmed cases by indirect sandwich ELISA test. Out of four major serotypes noticed O (50.38 %), A (30.53%), Asia 1 (19.08%), and C was not detected (Verma *et al.,* 2010).

5.1.1.3 Serotypes of FMD in Karnataka

The active and passive surveillance of foot and mouth Disease in Karnataka was conducted between 1977 to 2013. During the period 11,251 outbreaks were noticed mainly in cattle and buffalo in all 30 districts of Karnataka state. Most of the outbreaks were caused by serotype O (64.04%), followed by Asia 1 (19.87%) and A (12.27%). Serotype C has not been reported in Karnataka state since 1993. In recent years, serotype O (82.59%) is predominant, with the remaining outbreaks being almost equally caused by A (9.01%) and Asia 1 (8.40%). Serotype O was mainly associated with cattle in the epidemiology of FMD in Karnataka and in all the agroclimatic zone, found a significant relationship between the density of animals, number of outbreaks reported and number of cases (Hegde *et al.,* 2014).

5.1.2 Distribution of FMDV Serotypes

***Serotype O*:** Serotype O is the most common and widely distributed serotype, causing frequent outbreaks. It affects a wide range of host species and has numerous subtypes. The most widely studied and prevalent FMD serotype worldwide (Klein *et al.,* 2009). It has spread in East Asian countries which include Hong Kong, South Korea, North Korea, Japan, Mongolia, Eastern Russia, Taiwan and China (Lin *et al.,* 2010), (Zheng *et al.,* 2012), Knowles *et al.,* (2012), (Hui & Leung, 2012), (Valdazo-González *et al.,* 2014)). South East Asia countries include Myanmar, Malaysia, Vietnam, and Thailand (Khounsy *et al.,* 2008), (Nguyen, Lee, *et al.,* 2010; Nguyen, Park, *et al.,* 2010), (Abdul-Hamid *et al.,* 2011), (Lee *et al.,* 2011). Southern Asian countries include Iran, Iraq, Afghanistan, and Pakistan (Knowles *et al.,* 2009), (Jamal *et al.,* 2011), and (Upadhyaya *et al.,* 2014). Western Asian countries include Turkey, Jordan and Israel (Upadhyaya *et al.,* 2014). Central Asia includes Georgia, Kazakhstan and Kyrgyzstan (Brito *et al.,* 2017). Arabian Peninsula includes Saudi Arabia, United Arab Emirates, Bahrain and Kuwait(Valdazo-González *et al.,* 2014). North African Countries Libya, Egypt (Ahmed *et al.,* 2012; El-Shehawy *et al.,* 2014). In Indian subcontinent the serotype O was found in India, Sri Lanka, Bhutan, Bangladesh and Nepal (Di Nardo *et al.,* 2011; J. Mohapatra *et al.,* 2011; J. K. Mohapatra *et al.,* 2011; Nandi *et al.,* 2015; Sanyal *et al.,* 2010; Saravanan Subramaniam, Jajati K Mohapatra, *et al.,* 2013; Saravanan Subramaniam, Aniket Sanyal, *et al.,* 2013; Ullah *et al.,* 2015; Ullah *et al.,* 2014; Yuvaraj *et al.,* 2013). In Karnataka also, O serotype and cattle as the key indicator species in the epidemiology of FMD in Karnataka and found in all the districts(Hegde *et al.,* 2014).

***Serotype A*:** The Serotype A distribution was less prevalent compared to Serotype O but Serotype A also distributed in many of the countries, Serotype O and A have the widest global distribution and have been responsible for outbreaks in Europe, America, Asia and Africa. it was noticed in East Asia, South East Asia, Indian subcontinent, Southern Asia, Arabian Peninsula, Western Asia, Central Asia, North Africa(Brito *et al.,* 2017).

***Serotype Asia1*:** Asia 1 serotype is primarily found in the Indian subcontinent, it has also been sporadically reported in countries to the west and east of this region.

Periodically, the serotype has spread into the Middle East and occasionally reached Europe. However, it has not been reported from Africa or the Americas(Ansell *et al.,* 1994; Islam *et al.,* 2001; Schumann *et al.,* 2008; Valarcher *et al.,* 2008). The Asia 1 serotype was first detected in samples collected in India in 1951 through 1952 (Dhanda *et al.,* 1957) and later in Pakistan in 1954 (Brooksby & Rogers, 1957). The primary region where Asia 1 is endemic is the Indian subcontinent, which includes Afghanistan, India, Pakistan, Bhutan, and Nepal. In this region, outbreaks of the Asia 1 serotype occur regularly. FMDV in the West Bengal region of India, reported the recovery of the Asia 1 serotype from only 15% of the FMD cases examined between 1985 and 2002(Bhattacharya *et al.,* 2005). The Asia1 serotype also noticed in Karnataka in the year 2012(Hegde *et al.,* 2014).

Serotype C**:** Early 1920s first detected in Europe and mainly affected to pigs and cattle with less infection. But after vaccination in 1990 in Europe the serotype C was not noticed. Between 1994 and 2004, serotype C of a particular disease had not been reported in South America. However, in 2004, four small outbreaks of serotype C were detected in the Amazon region (Paton *et al.,* 2021). The last report of Serotype C was noticed in Ethiopia during 2005 (Rweyemamu *et al.,* 2008).In India also no cases were recorded after 1996 (Bhattacharya *et al.,* 2005).

Southern African Territories serotypes (SAT 1-3)**:** only sub-Saharan Africa is affected by the SAT 1-3 viruses.

5.2 Materials and Methods

5.2.1 Serotype data collection.

Village wise serotype data from the year 2012 to 2021 were collected from the FMD Regional Centre, IAH & VB, Bengaluru, and Karnataka, India. Village wise serotype master data was prepared, and the spatial mapping of serotype data was done using the QGIS software (3.28.0). The visualization of the data was performed in QGIS.

5.3 Results

The maximum number of FMD outbreaks (n=448) was observed in 2013. In Karnataka, serotype O is more prevalent compared to all other serotypes. In Karnataka, all 31 districts have reported FMDV serotype O. Bangalore rural district has reported the highest number of outbreaks followed by Ramanagara, Belgaum, Tumkur, Bangalore Urban, Mandya, Chikkaballapura, Kolar, Davangere, Shivamogga, Chikkamagaluru, Hassan, Mysuru, Gadag, Dakshina Kannada, Koppal, Haveri, Bagalkot, Uttara Kannada, Chitradurga, Raichur, Chamarajanagara, Gulbarga, Dharwad, Udupi, Bidar, Bellary, Bijapur, Kodagu, and Vijayanarag reported very less number of FMD outbreaks (Figure 5.3.1).

The map shows the distribution of Serotype O in Karnataka state. According to the map of the distribution of serotype O Bangalore rural and Ramanagara districts show more number of serotype O category (91-113) followed by, Belagavi, Tumkur, Bengaluru Urban, Mandya, and Chikkaballapura belong to the categories (68-91) and next comes Kolar and Davangere (46-68) category, Shivamogga, Chikkamagaluru, Hassan, and Mysuru belongs to (23-46) category and all other Gadag, Dakshina Kannada, Koppal, Haveri, Bagalkot, Uttara Kannada, Chitradurga, Raichur, Chamarajanagara, Gulbarga, Dharwad, Udupi, Bidar, Bellary, Bijapur, Kodagu, and Vijayanarag districts category (1-23) (Figure 5.3.2). The year wise serotypes distribution from 2012 to 2021 map is shown in Figures 5.3.3 to 5.3.7 Serotype O was reported maximum in the year 2013 followed by 2021, 2018 and 2017.

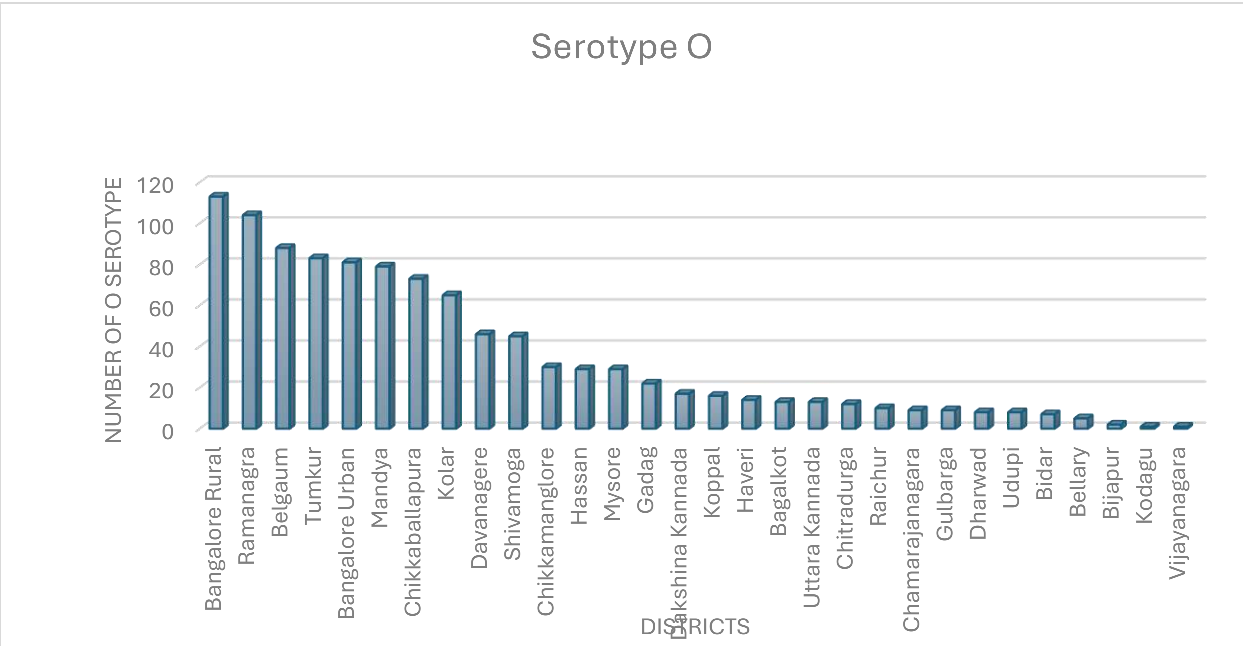


Figure 5.3.1 *Bar diagram for district wise FMDV serotype O distribution (2012-2021)*

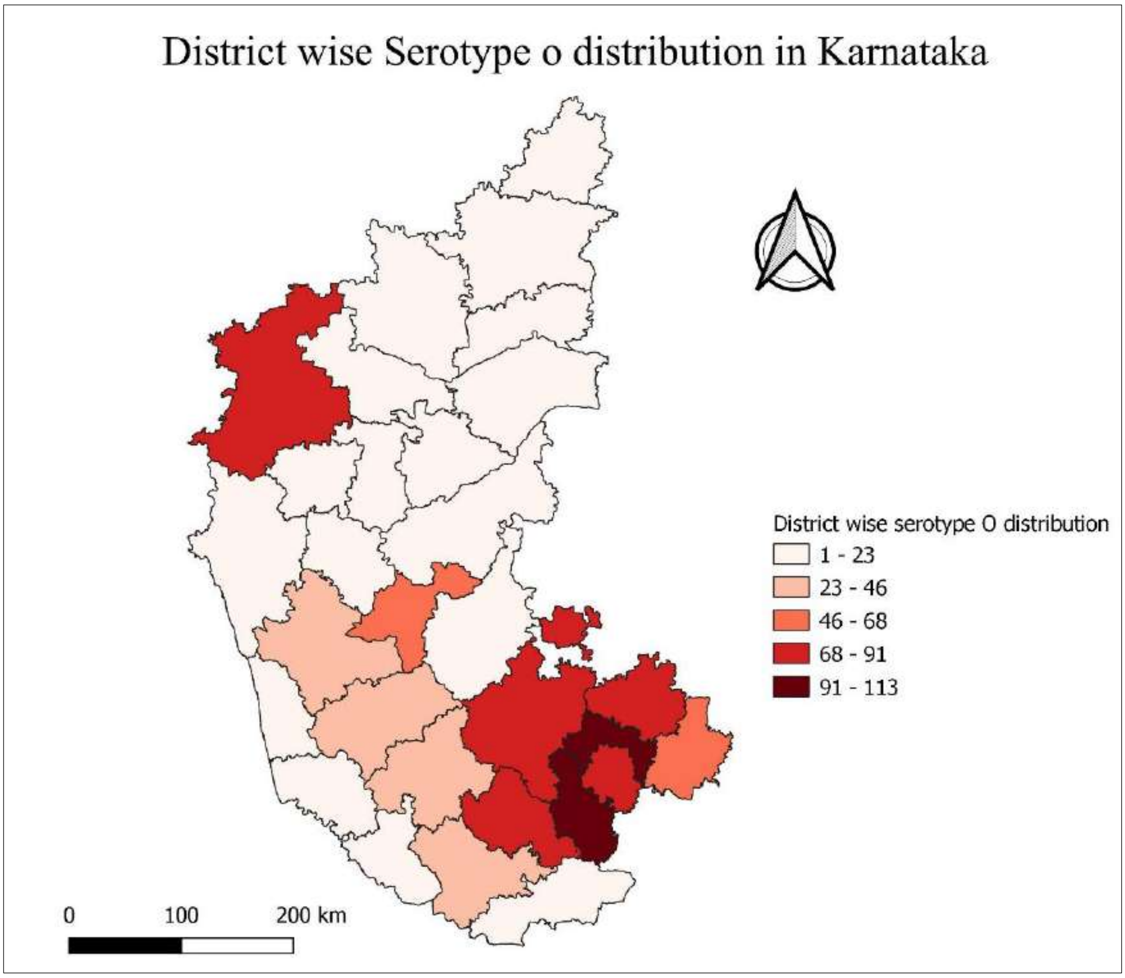
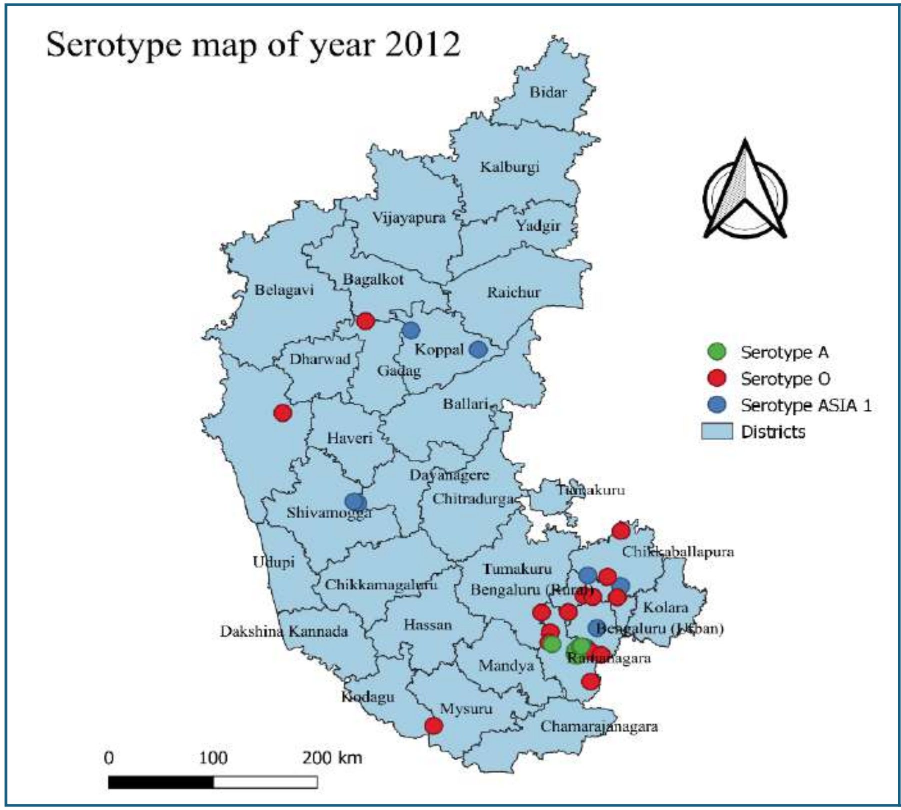


Figure 5.3.2 *Map of Serotype O distribution in Karnataka state.*



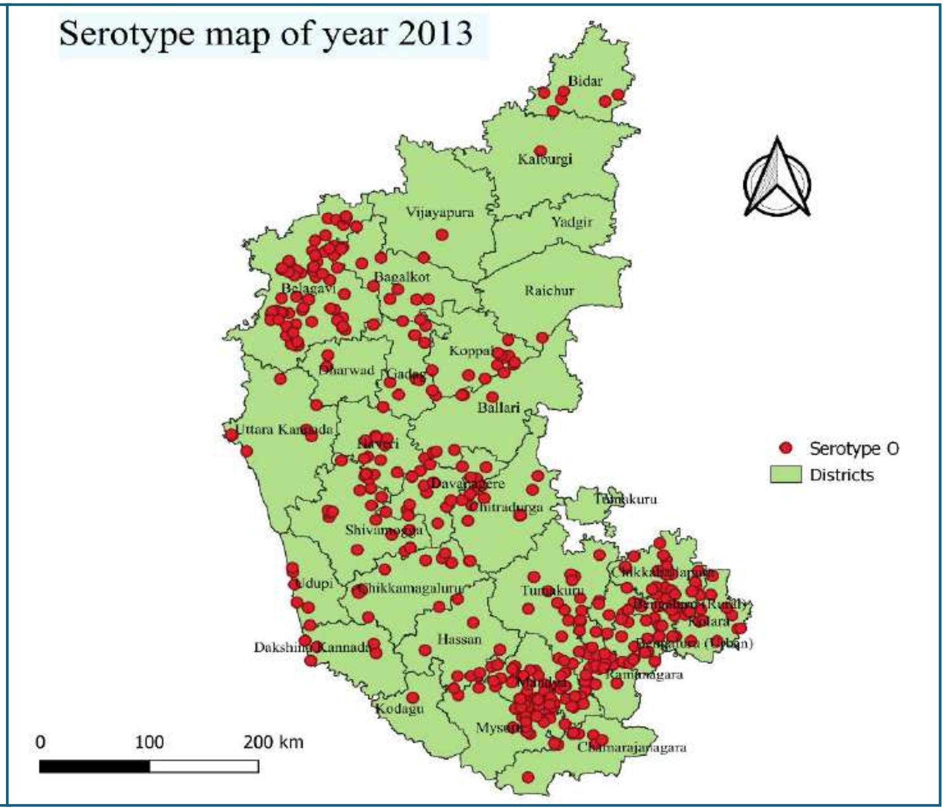


Figure 5.3.3 *Serotype maps for the years 2012 and 2013*

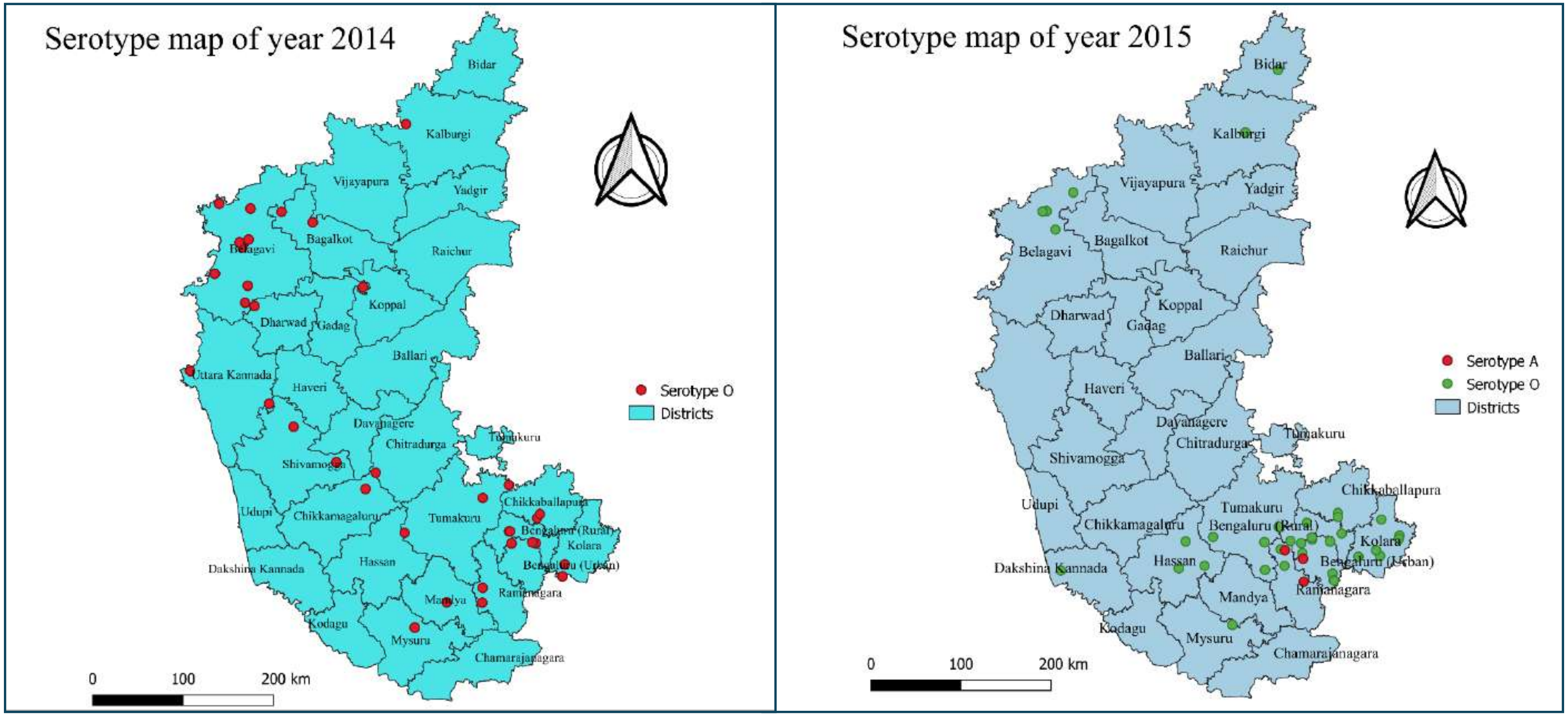


Figure 5.3.4 *Serotype maps for the years 2014 and 2015*

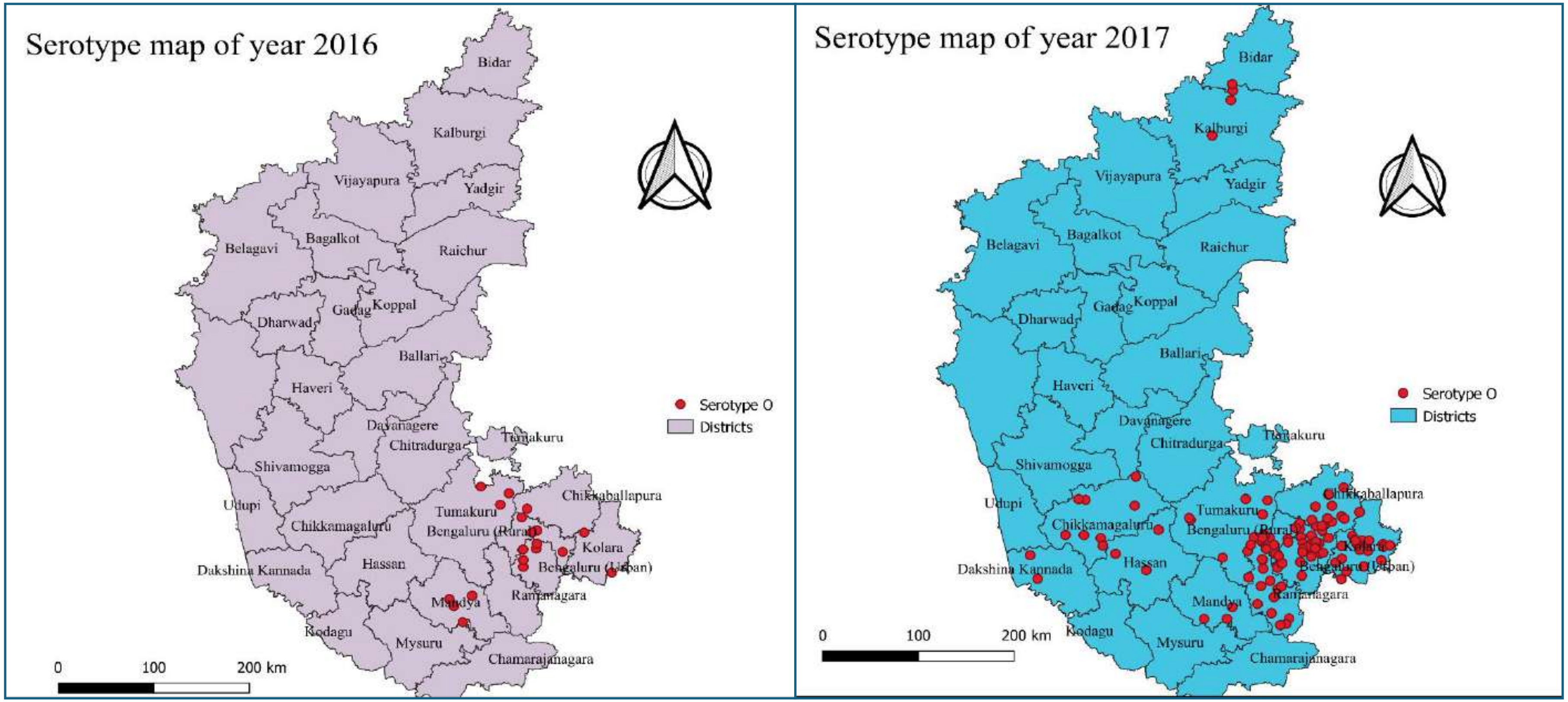


Figure 5.3.5 *Serotype maps for the years 2016 and 2017*

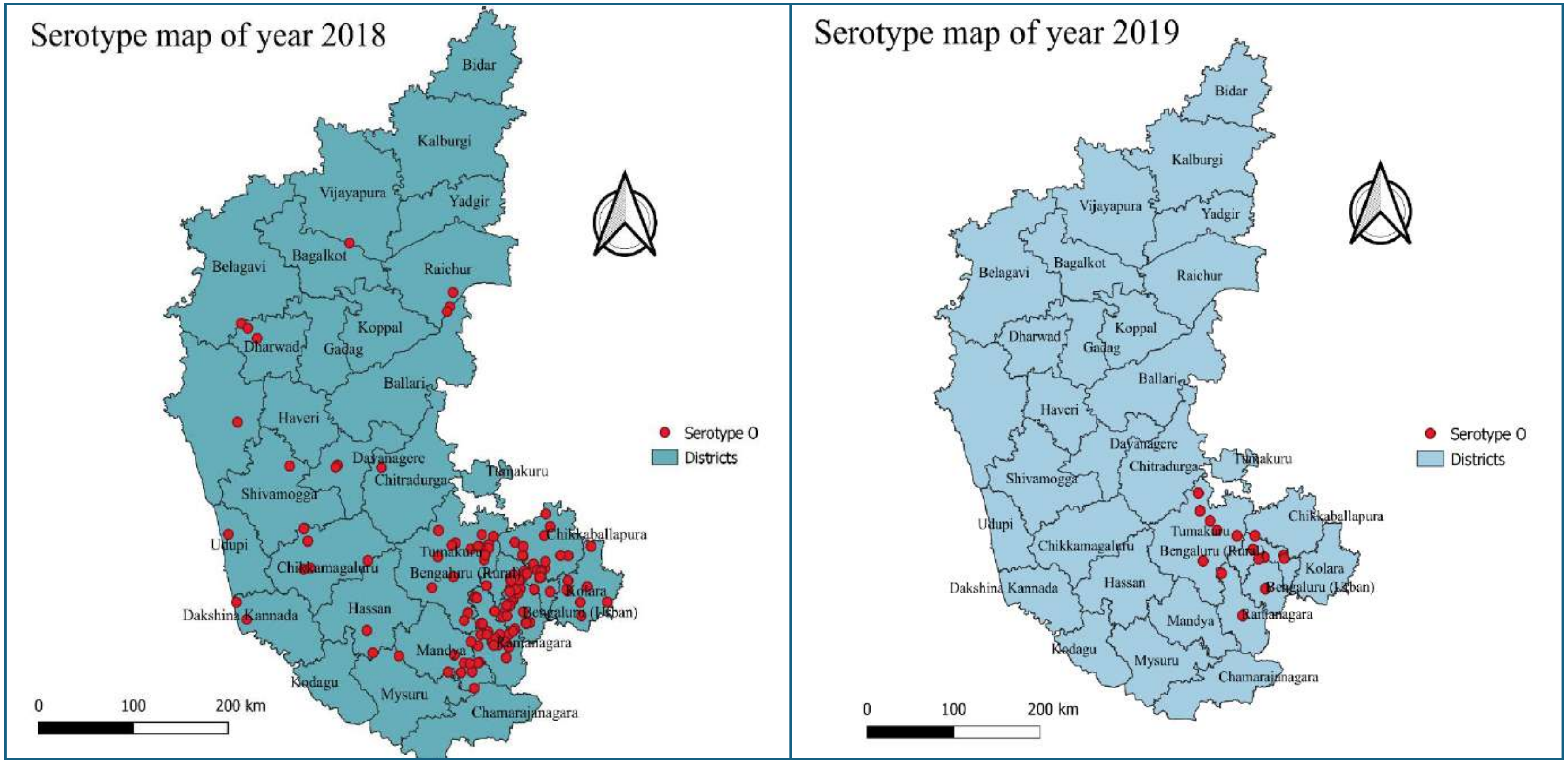


***Figure 5.3.6** Serotype maps for the years 2018 and 2019*

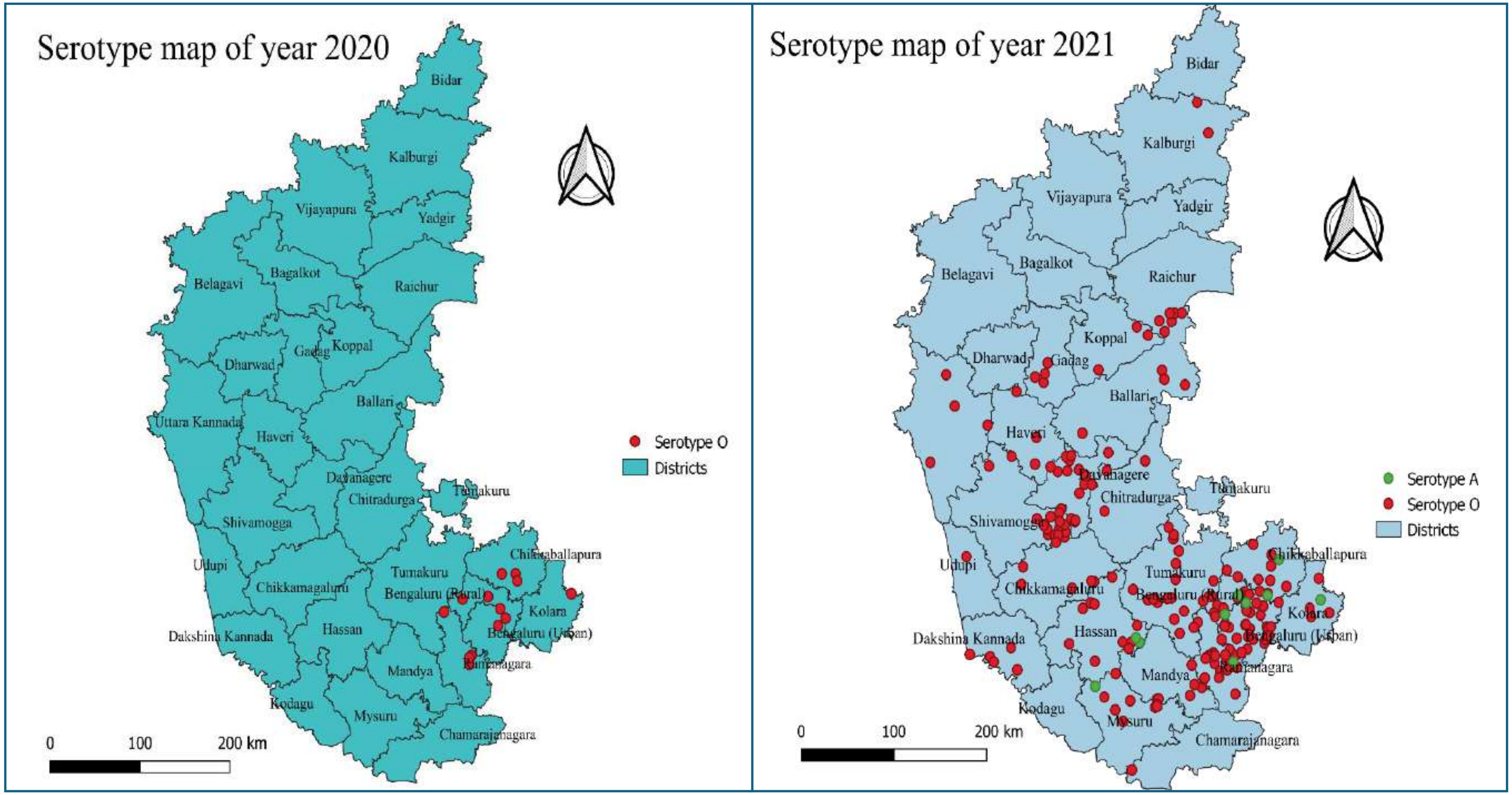


Figure 5.3.7 *Serotype maps for the years 2020 and 2021*

5.4 Discussion

In this study, collated data on serotype distribution in Karnataka state of India. The spatial distribution of serotypes was prepared using GIS (Geographical Information System). Overall, serotype O was predominantly distributed across districts of Karnataka with the year 2013 reporting maximum outbreaks. In one study, ELISA and multiplex PCR was used to type the serotypes and found that serotype O and Asia 1 were responsible for the outbreaks (Rout *et al.,* 2014). It has spread in East Asian countries which include Hong Kong, South Korea, North Korea, Japan, Mongolia, Eastern Russia, Taiwan and China (Lin *et al.,* 2010), (Zheng *et al.,* 2012), Knowles et al. (2012), (Hui & Leung, 2012), (Valdazo-González *et al.,* 2014)). It is also reported from South East Asia countries including Myanmar, Malaysia, Vietnam, and Thailand (Khounsy *et al.,* 2008), (Nguyen, Lee, *et al.,* 2010; Nguyen, Park, *et al.,* 2010), (Abdul-Hamid *et al.,* 2011), (Lee *et al.,* 2011), Southern Asian countries such as Iran, Iraq, Afghanistan, and Pakistan (Knowles *et al.,* 2009), (Jamal *et al.,* 2011), and (Upadhyaya *et al.,* 2014), Western Asian countries such as Turkey, Jordan and Israel (Upadhyaya *et al.,* 2014). In Indian subcontinent the serotype O was found in India, Sri Lanka, Bhutan, Bangladesh and Nepal (Di Nardo *et al.,* 2011; J. Mohapatra *et al.,* 2011; J. K. Mohapatra *et al.,* 2011; Nandi *et al.,* 2015; Sanyal *et al.,* 2010; Subramaniam, Mohapatra, *et al.,* 2013; Subramaniam, Sanyal, *et al.,* 2013; Ullah *et al.,* 2015; Ullah *et al.,* 2014; Yuvaraj *et al.,* 2013). Serotype O is reported from Karnataka from many districts (Hegde *et al.,* 2014). The Serotype A distribution is less prevalent compared to Serotype O. Serotype O and A have the widest global distribution and have been responsible for outbreaks in Europe, America, Asia and Africa. it was noticed in East Asia, Southeast Asia, Indian subcontinent, Southern Asia, Arabian Peninsula, Western Asia, Central Asia, North Africa (Brito *et al.,* 2017). Asia 1 serotype is primarily found in the Indian subcontinent, it has also been sporadically reported in countries to the west and east of this region. Periodically, the serotype has spread into the Middle East and occasionally reached Europe. However, it has not been reported from Africa or the Americas (Ansell *et al.,* 1994; Islam *et al.,* 2001; Schumann *et al.,* 2008; Valarcher *et al.,* 2008). The Asia 1 serotype was first detected in samples collected in India in 1951 through 1952 (Dhanda *et al.,* 1957) and later in Pakistan in 1954 (Brooksby & Rogers, 1957). The Asia 1 serotype was reported from West Bengal state of India, (Bhattacharya *et al.,* 2005). The Asia1 serotype was also observed in Karnataka during the year 2012

Hegde *et al.,* 2014). It was first detected in early 1920s in Europe and mainly affected pigs and cattle with less infection. However, in 2004, four small outbreaks of serotype C were detected in the Amazon region (Paton *et al.,* 2021). The last report of Serotype C was noticed in Ethiopia during 2005 (Rweyemamu *et al.,* 2008). In India there were no reports of Asia 1 since 1996 (Bhattacharya *et al.,* 2005). Only sub-Saharan Africa is affected by the SAT 1-3 serotypes.

5.5 Conclusion

Analysis of Foot and Mouth disease serotype data in Karnataka for the period of 2012-2021 was carried out and revealed that the serotype O is the main serotype in the state. found that 97% of the outbreaks occurred with serotype O. The Yearly trends of FMD shown that the year 2013 was noticed maximum number of outbreaks and least number of outbreaks in the year 2020 (n=13). Bengaluru rural and Ramanagar districts reported maximum serotype O outbreaks and needs targeted surveillance and studies to identify factors responsible for variation in the distribution of outbreaks in other districts. The GIS maps will be helpful for policy makers to visualise the spatial distribution of FMD outbreaks due to different serotypes and plan for intervention strategies for effective prevention and control of disease in Karnataka state.

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Appendix A: Conference Certificates

THE 8TH INTERNATIONAL MEETING ON
EMERGING DISEASES AND SURVEILLANCE (IMED)
NOVEMBER 4-6, 2021

Certificate of Attendance

This is to confirm that

Veena R

REGISTRATION CONFIRMATION #: 56720843

has participated in the IMED 2021 conference.

NOVEMBER 6, 2021

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XXXIV Annual Convention of Indian Association of Veterinary Microbiologists, Immunologists and Specialists in Infectious Diseases
and
National Conference
on
"Current Trends in Immunodiagnostics & Vaccinology for Health of Livestock & Poultry"

Certificate

This is to certify that Dr. .... VEENA R. ....from ICAR- NIVEDI, Yelahanka, Bengaluru, Karnataka has participated and presented Invited Paper/Research Paper (Oral/Poster) entitled "Understanding the influence of climate and host factors on occurrence of Foot and Mouth Disease in Karnataka" in XXXIV Annual Convention of Indian Association of Veterinary Microbiologists, Immunologists and Specialists in Infectious Diseases and National Conference organized by the Department of Veterinary Microbiology, ICAR-CAFT, College of Veterinary Sciences, LUVAS, Hisar from May 27 - 28, 2022.

Dr. A. K. Tiwari General Secretary IAVMI	**Dr. Rajesh** Organizing Secretary	**Dr. Gulshan Narang** Chairman Organizing Committee

UNIVERSITY OF AGRICULTURAL SCIENCES, BANGALORE
ALL INDIA AGRICULTURAL STUDENTS ASSOCIATION, NEW DELHI
INDIAN COUNCIL OF AGRICULTURAL RESEARCH, NEW DELHI

INTERNATIONAL CONFERENCE ON ADVANCES IN AGRICULTURE AND FOOD SYSTEM TOWARDS SUSTAINABLE DEVELOPMENT GOALS (AAFS-2022) : 22 - 24 AUGUST 2022

Certificate

This is to certify that Dr./Mr./Ms. Veena R., Women Scientist - B *of* ICAR - NIVEDI, Bengaluru - 64 *participated and presented (poster/oral presentation) and delivered their talk on* Identification of Managemental Risk factors for occurance of FMD in Karnataka using statistical methods *under the theme entitled 'Advances in Dairy and Veterinary Sector Towards Sustainable Development Goals' and* ~~*secured*~~ — *position in the International Conference on 'Advances in Agriculture & Food System Towards Sustainable Development Goals' held from 22 - 24th, August, 2022 at University of Agricultural Sciences, Bangalore*

Ashok Kumar Singh	**S. Rajendra Prasad**	**Vivek Saurabh**
DDG, Agril. Extension, ICAR	Chairperson, Organising Committee	Co-Chairperson, Organising Committee
Chairman, Steering Committee	& Vice-Chancellor, UAS, Bangalore	National President, AIASA

Appendix B: First Paper

Full Length Research Article

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Spatial Mapping of Foot and Mouth Disease Serotypes in Karnataka using Geographical information System (GIS)

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Abstract

Foot and mouth disease (FMD) is an economically important disease affected domestic livestock. There are seven serotypes of the FMD virus reported globally. In India, serotypes O, A, C and Asia 1 are reported. The spatial distribution of different serotypes is not known. In this study, we used Geographical Information System (GIS) for mapping of different serotypes in different years for Karnataka state. We found that serotype O is the main serotype in Karnataka. The serotype distribution maps will be useful for planning FMD surveillance and disease control strategies for the state of Karnataka and can be extended to other states of India.

Key words: Geographical Information System, Spatial distribution, Foot and Mouth Disease, Serotypes of FMD, Surveillance

Foot and mouth disease (FMD), which affects animals cloven footed animals and cause economic losses. There are seven serotypes of the FMD virus (FMDV) namely: O, A, C, SAT 1, SAT 2, SAT 3, and Asia 1 [1]. Clinically, it is difficult to differentiate between FMD and other vesicular diseases such as swine vesicular disease, vesicular stomatitis, vesicular exanthema, and infection with the Seneca Valley virus.

Serotype O is the most widely studied and prevalent Foot and mouth disease (FMD) serotype worldwide [2]. It is the most common and widely distributed serotype, causing frequent outbreaks in India. Serotype O is known to be the most prevalent and widely studied serotype of FMD globally, with frequent outbreaks occurring in India, particularly in Karnataka. Despite its significance, there has been a lack of GIS-based mapping of livestock disease outbreaks in this region [3]. It affects a wide range of host species and has numerous subtypes. GIS provides a powerful tool for visualizing and analyzing spatial data, allowing for the identification of high-risk areas and the planning of intervention strategies. By incorporating serotype distribution data, we aimed to create spatial maps that can be used by disease managers and policymakers to allocate resources effectively and implement timely control measures to prevent and mitigate outbreaks [4]. Spatial mapping of livestock disease outbreaks using Geographical Information System (GIS) is very powerful tool for visualizing of outbreaks and planning for intervention strategies in high-risk areas. The spatial maps are useful for diseases managers, policy makers in allocating resources and timely control of outbreaks and prevention [5]. The use of GIS in mapping of livestock diseases has not been used in India and in Karnataka. In this study we used serotype distribution data for make spatial maps [6].

By utilizing GIS technology to map the distribution of FMD serotype O outbreaks, we can improve the allocation of resources and the implementation of control measures to reduce the impact of this devastating disease on livestock populations and agricultural economies. Our spatial maps provide valuable information for policymakers, veterinarians, and other stakeholders involved in Foot and mouth disease (FMD) control efforts, facilitating more informed decision-making and more effective disease management practices.

MATERIALS AND METHODS

Serotype data collection

Village-wise serotype data from the year 2012 to 2021 were collected from the Foot and mouth disease (FMD) Regional Centre, IAH & VB, Bengaluru, and Karnataka, India. Village-wise serotype master data was prepared, and the spatial mapping of serotype data was done using the QGIS software (3.28.0). Our study collected data on the distribution of Foot and mouth disease (FMD) serotype O outbreaks in Karnataka, including information on the affected host species and subtype variations. We then employed GIS techniques to overlay this data onto geographic maps, allowing us to visualize the spatial distribution of outbreaks across the region. By identifying hotspots of Foot and mouth disease (FMD) serotype O activity, we can better understand the epidemiology of the disease and prioritize areas for targeted intervention efforts.

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Appendix C: Questionnaire

Questionnaire for Outbreak Investigation of Foot and Mouth Disease in Animals

Instructions to fill the questionnaire

1. This questionnaire should be used by trained staff to whom it is given and not by any other person. If found any copy it can be mailed to the address given.
2. This questionnaire should only be used in suspected animal cases of Foot and Mouth Disease.
3. This questionnaire should be used to interview farmers/persons with livestock in the village.
4. **Please take verbal consent of the farmer/person whom you are interviewing and explain the purpose of questionnaire**
5. Please be polite while asking questions to the farmer/person and not to force him/her to answer your questions
6. Carry GPS with you to record reading of each household and label it. GPS readings needs to be taken wherever mentioned in the questionnaire. Make yourselves familiar with the GPS before going to field
7. Carry sufficient copies of the questionnaire to field.
8. Flow the case definition chart of the tests from the detection of suspected cases by clinical inspection to the disease confirmation.
9. Spend sufficient time with the each farmer to collect the complete and right information.
10. Make the separate note of the information which you feel special and important while taking interview.
11. This questionnaire can be used for 10 households and more copies can be used for completing the survey in the village.
12. Interview all the farmers with livestock population in the village.

Case Definition for Foot and Mouth Disease (FMD)

FMD can be suspected in cattle, sheep, goats, pigs and other cloven-hoofed animals. There are seven serotypes of FMD viruses worldwide. The serotypes identified in India include O, A and Asia1.

1. **Clinical criteria:**

   FMD should be suspected when a combination of the following 2-3 clinical signs are observed.
   - High Fever.
   - Salivation.
   - Blisters/ Vesicles in the oral cavity and interdigital space of feet.
   - In lactating animals, significant drop in milk production.
   - Weight loss.
   - Loss of appetite.
   - Quivering lips and frothing of mouth.
   - Cows may develop blisters on teats.
   - Lameness in a number of animals.
2. **Epidemiological criteria**
   - Recent climate/weather change like rainfall
   - High Morbidity and low mortality in animals.
3. **Laboratory criteria**
   - Demonstration of FMD virus antigen using sandwich ELISA
   - Demonstration of FMD non-structural antibodies using ELISA.
   - PCR based viral nucleic acid detection

Suspected case of FMD: If it satisfies criteria 1 then case can be classified as suspected case of FMD

Probable case of FMD: If it satisfies criteria 1 and criteria 2, then it can be classified as probable case of FMD

Confirmed case of FMD: If it satisfies criteria 1, 2 and 3 then it can be classified as confirmed case of FMD. If there is no information on criteria 1 and 2 then criteria 3 (laboratory confirmed) can be used to confirm a case of FMD.

Questionnaire for FMD outbreak Investigation

1. Basic Information with Livestock Details											
1.2 Date of Survey											
1.3. Village Name											
1.4. Taluka											
1.5. District											
1.1. House Hold Numbers		H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
1.6. GPS reading of the household- Longitude											
1.7. GPS reading of the household- Latitude											
1.8. Farmer Name											
1.9. Contact Number											
1.10. Total Number of Live stock											
Cattle	Total										
	Affected										
Sheep	Total										
	Affected										
Goat	Total										
	Affected										
Pigs	Total										
	Affected										
1.11. Awareness about Foot and mouth disease (FMD)**(No-0,Yes-1)**											
1.12. Vaccination Done against FMD?											

(No-0,Yes-1)										
1.13. Date of first case Occurrence in the household										
1.14. Date of last FMD Vaccination in the household										
2. Source of fodder										
a. Grazing – **1**										
b. Stall feeding**-2**										
c. Both**- 3**										
3. Source of Water										
a. Tap water – **1**										
b. Pond water– **2**										
c. Both– **3**										
4. Age of the animal affected and number in their household										
a. 0-6 months– **1**										
b. 6 months -1 year– **2**										
c. 1-2 year – **3**										
d.2 years & above– **4**										
5. Breed specific details of the affected animals(Including number)										
a. Indigenous breed – **1**										
b. H.F.cross– **2**										
c. Jersey cross										
6. Contact Tracing										
6.1. Were the animals recently purchased? **(No-0,Yes-1)**										
6.2. If yes, from where and when it was purchased?										

(Name of the village)										
6.3. Is there any migratory flock in your village? **(No-0,Yes-1)**										
6.4. If yes, since how many days are they in your village?										
7.Animal housing and rearing practices										
7.1. Housing system (Temporary/kachha**-1**, Permanent/Pakka**-2**, Open yard**-3**)										
7.2 Are the animals closely tied/sheltered under one roof **(No-0,Yes-1)**										
7.3. Do you use disinfectant for cleaning the shed **(No-0,Yes-1)**										
7.4. Is the animal shed properly ventilated? **(No-0,Yes-1)**										
7.5. Is the shed close to continuously-flooded swamps **(No-0,Yes-1)**										
7.6. Source of water for the livestock (Rivers/ stream/channels**-1** (flowing),										

tanks/ponds **-2** (stagnant), municipality taps-**3**, bore wells-**4**,other-**5**										
7.7. History of FMD outbreak in the recent past in the neighbouring villages/locality **(No=0, Yes=1)**										
7.8. Number of animals affected or suspected for FMD in the surrounding locality										
7.9 Species affected										
7.10. Recent Incidence of animal mortality in the locality (month/season)										
7.11. Age of the animals suspected/affected with disease (month/ year)										

Any other relevant information:

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