RISK ESTIMATION AND PREDICTION OF BLUETONGUE DISEASE OUTBREAK AMONG SHEEP AND GOATS IN KARNATAKA USING APPROPRIATE STATISTICAL MODELS

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IV RESULTS AND DISCUSSION

This chapter is designed to present the results and discussions under the objectives of the study. The study is restricted to data at the district level, Findings are presented under the following heads:

4.1 Descriptive statistics of Bluetongue disease outbreak among Sheep and Goats

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4.1 Descriptive statistics of Bluetongue disease outbreak among Sheep and Goats

A descriptive statistic is a summary statistic that quantitatively describes or summarizes features from a collection of information. The descriptive statistics used in this

study are the process of using and analysing those statistics for the Bluetongue disease outbreak among Sheep and Goats by using 15 years of data from 2015 to 2019 in all 30 districts of Karnataka.

4.1.1 Outbreak

To develop a statistical model which can forewarn the outbreak of Bluetongue disease among Sheep and Goats in Karnataka, the data on the disease outbreak in the districts of Karnataka was obtained from the Department of Animal Husbandry, Government of Karnataka. The data collected were classified into district level based on the years, months and seasons of occurrences of the outbreak.

(a) Year-wise

The data were tabulated according to the year-wise distribution of Bluetongue disease outbreak during the period 2005-2019 to understand the occurrences of the disease at the district level. Year-wise distribution of Bluetongue disease outbreak among Sheep and Goats is depicted in Table 4.1 and Fig. 4.1. Data indicated highest number of disease outbreaks was recorded in the year 2005 (286) which contribute 37.63 per cent of the total disease outbreak in Karnataka followed by 2008 (21.84%), 2016 (9.87%), 2009 (8.29%), 2015 (6.45%), 2010 (4.08%), 2006 (3.68%), 2011 (3.69%), 2014 (1.97%), 2019 (0.79%), 2013 (0.66%), 2017 (0.66%), 2018 (0.26%), 2007 (0.13%) and no disease outbreak in in 2012.

As such there is no pattern observed in outbreak of Bluetongue disease among Sheep and Goats from year to year and the variation may be due to the fact that the factors favouring the disease are different in each year in each district.

(b) Month-wise

The data were tabulated according to the month-wise occurrence of Bluetongue disease outbreak during the period 2005-2019 to find out any month-wise pattern in the outbreak. Month-wise distribution of Bluetongue disease outbreak among Sheep and Goats is depicted in Table 4.2 and Fig. 4.2.

Table 4.1: Year-wise distribution of Bluetongue disease outbreak among Sheep and Goats (2005-2019)

Sl. No.	Year	Bluetongue disease outbreak among Sheep and Goats	
		Number	Percentage
1	2005	286	37.63
2	2006	28	3.68
3	2007	1	0.13
4	2008	166	21.84
5	2009	63	8.29
6	2010	31	4.08
7	2011	28	3.69
8	2012	0	0.00
9	2013	5	0.66
10	2014	15	1.97
11	2015	49	6.45
12	2016	75	9.87
13	2017	5	0.66
14	2018	2	0.26
15	2019	6	0.79
	Total	**760**	**100.00**

Table 4.2: Month-wise distribution of Bluetongue disease outbreak among Sheep and Goats (2005-2019)

Months	Bluetongue disease outbreak among Sheep and Goats	
	Number	Percentage
January	101	13.29
February	41	5.39
March	15	1.97
April	0	0
May	4	0.53
June	1	0.13
July	12	1.58
August	0	0
September	13	1.71
October	80	10.53
November	389	51.18
December	104	13.69
Total	**760**	**100.00**

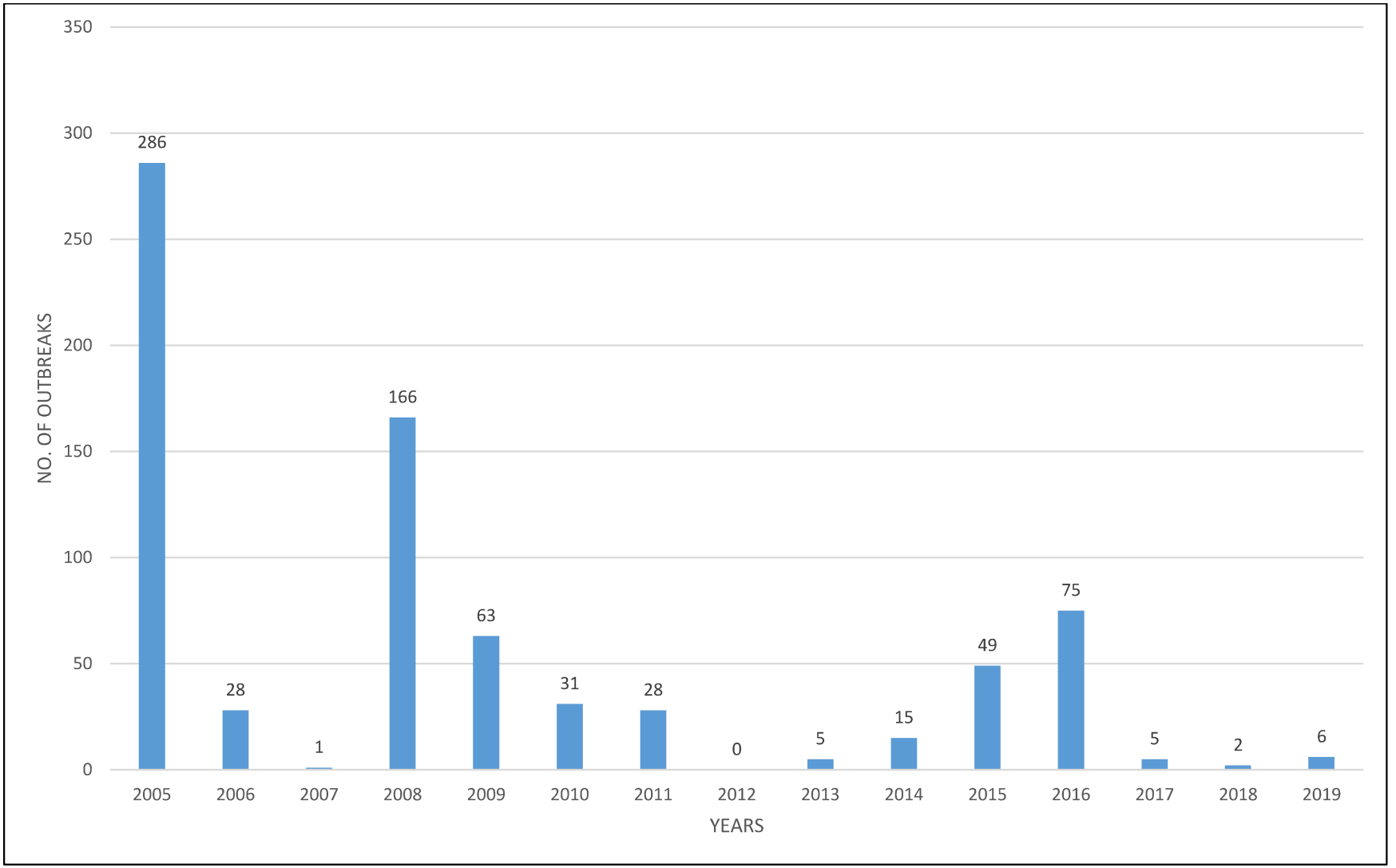

Fig. 4.1: Year wise distribution of Bluetongue disease outbreak among Sheep and Goats (2005-2019)

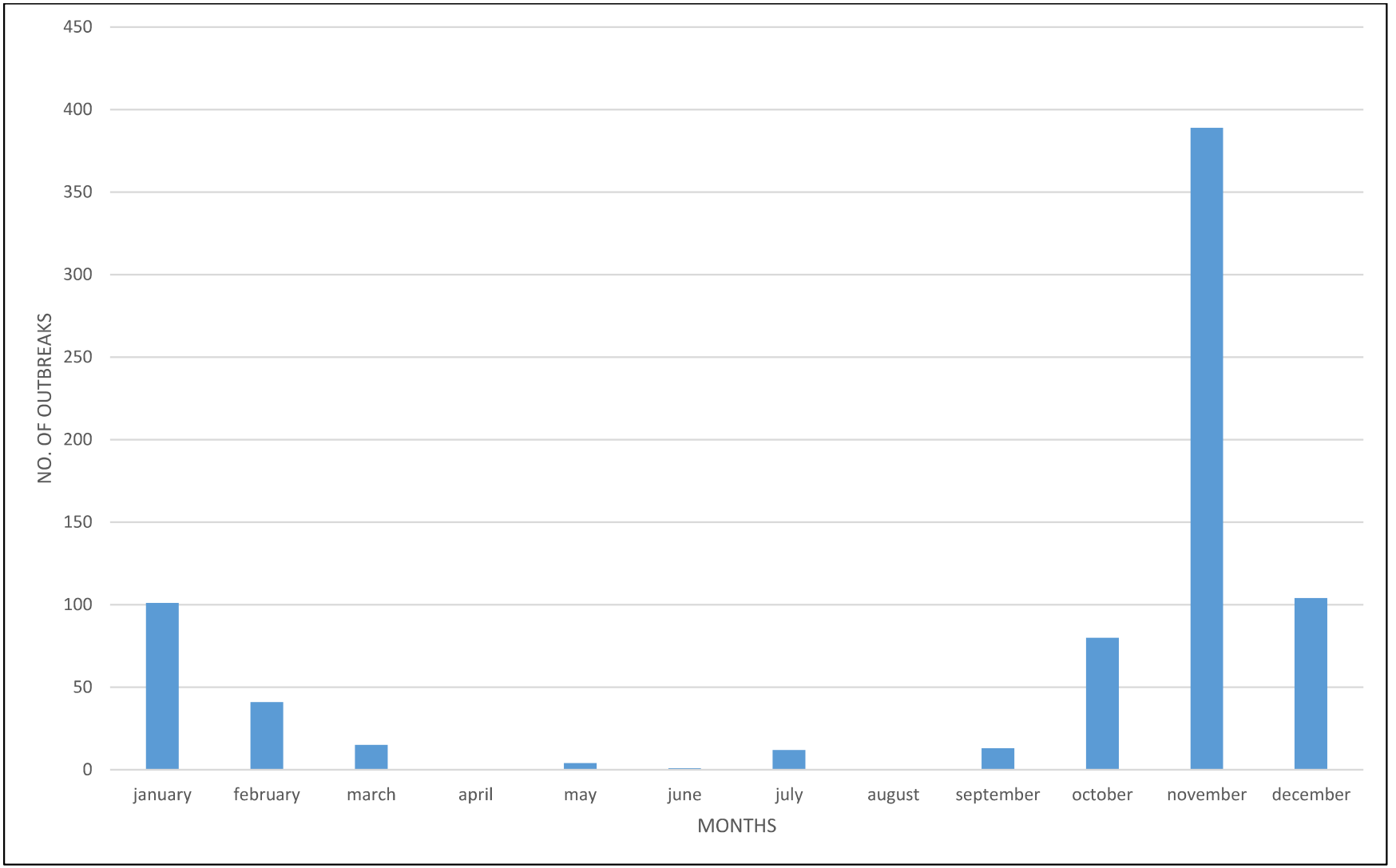

Fig. 4.2: Month wise distribution of Bluetongue disease outbreak among Sheep and Goats (2005-2019)

Data revealed that the number of disease outbreaks was highest during the month of November (389) which accounts for 51.18 per cent of the total disease outbreak in Karnataka followed by December (13.69%), January (13.29%), October (10.53%), February (5.39%), March (1.97%), September (1.71%), July (1.58%), May (0.53%), June (0.13%) and no disease outbreak in April and August.

As such, there is a pattern observed in outbreak of Bluetongue disease from November to January due to cold weather influencing the disease in these months in each year in each district.

(c) District-wise

The data were tabulated according to different districts to understand the occurrences of the disease at the district level during the period of 2005 to 2019. District-wise distribution of Bluetongue disease outbreak among Sheep and Goats is depicted in Table 4.3 and Fig. 4.3.

Data shows that out of 30 districts in Karnataka, 17 districts have reported Bluetongue disease during the period from 2005 to 2019. Among the districts, Tumakuru was found the highest number of outbreaks (128) which contributed 39.21 per cent of the total disease outbreak in Karnataka followed by Chitradurga (16.05%), Belagavi (7.11%), Chikkaballapura (7.11%), Bagalakote (6.45%), Koppal (5.65%), Davanagere (4.34%), Ballari (4.08%), Kolar (3.95%), Haveri (1.71%), Gadag (1.05%), Mandya (0.92%), Bengaluru rural (0.79%), Raichur (0.66%), Shivamogga (0.53%), Mysuru (0.26%) and Hassan (0.13%).

As such there is no pattern observed in outbreak of Bluetongue disease from district to district and the variation may be due to the fact that the factors causing the disease are different in each district.

(d) Season-wise

As one of the important cause of Bluetongue disease outbreak is rainfall, the study is conducted in different seasons and they were classified into pre-monsoon, monsoon and post-monsoon.

Table 4.3: District-wise distribution of Bluetongue disease outbreak among Sheep and Goats (2005- 2019)

Sl. No.	District	Bluetongue disease outbreak among Sheep and Goats	
		Number	Percentage
1	Tumakuru	128	39.21
2	Chitradurga	122	16.05
3	Belagavi	54	7.11
4	Chikkaballapura	54	7.11
5	Bagalakote	49	6.45
6	Koppal	43	5.65
7	Davanagere	33	4.34
8	Ballari	31	4.08
9	Kolar	30	3.95
10	Haveri	13	1.71
11	Gadag	8	1.05
12	Mandya	7	0.92
13	Bengaluru Rural	6	0.79
14	Raichur	5	0.66
15	Shivamogga	4	0.53
16	Mysuru	2	0.26
17	Hassan	1	0.13
18	Bengaluru Urban	0	0.00
19	Bidar	0	0.00
20	Vijayapura	0	0.00
21	Chamarajanagar	0	0.00
22	Chikkamagaluru	0	0.00
23	Dakshina Kannada	0	0.00
24	Dharwad	0	0.00
25	Kalaburagi	0	0.00
26	Kodagu	0	0.00
27	Ramanagara	0	0.00
28	Udupi	0	0.00
29	Uttara Kannada	0	0.00
30	Yadgir	0	0.00
	Total	**760**	**100.00**

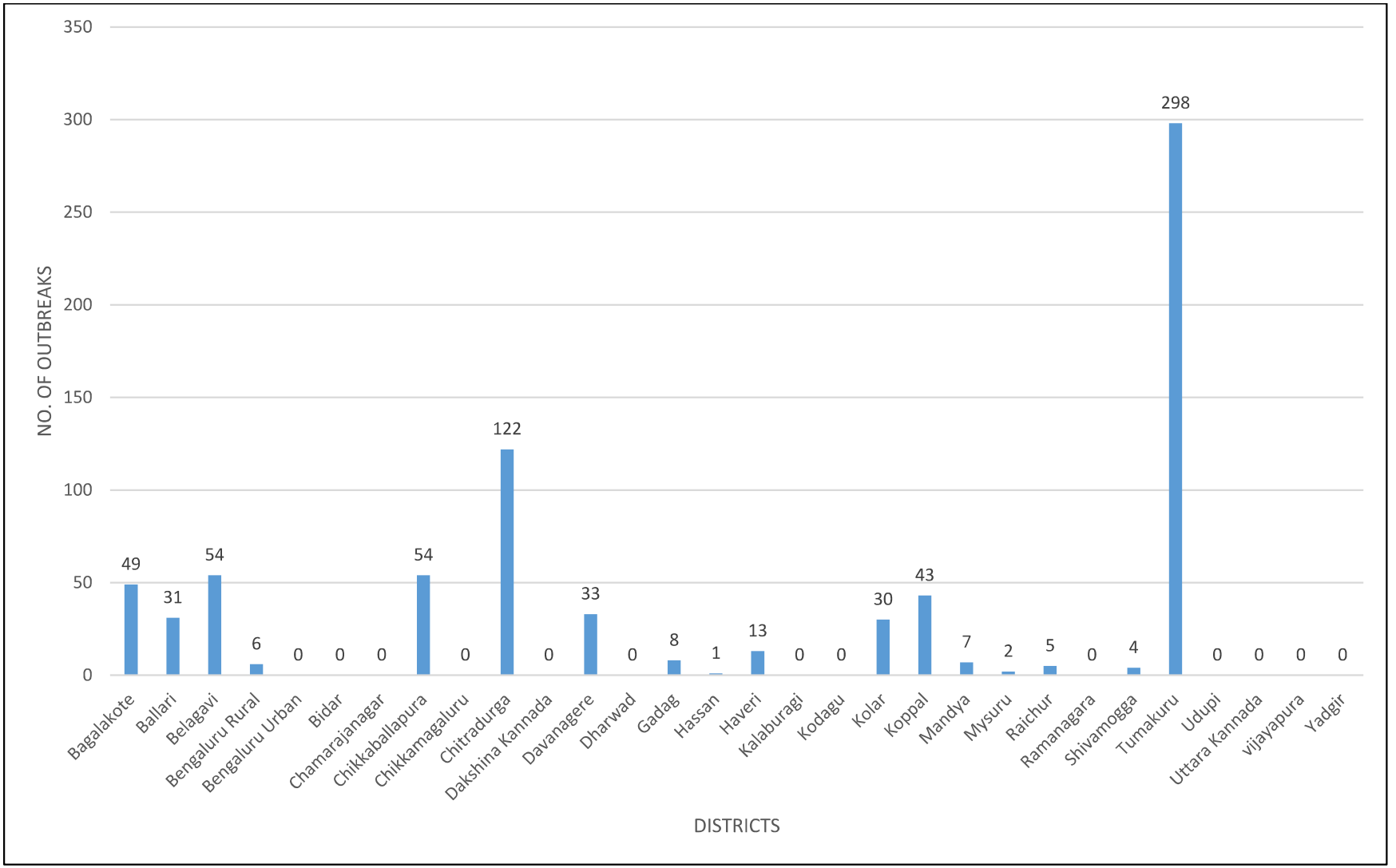

Fig. 4.3: District wise distribution of Bluetongue disease outbreak among Sheep and Goats (2005- 2019)

Table 4.4: Season-wise distribution of Bluetongue disease outbreak among Sheep and Goats (2005-2019)

Sl. No.	Districts	Bluetongue disease outbreak among Sheep and Goats			
		Pre-monsoon	Monsoon	Post-monsoon	Total
1	Bagalakote	0	49	0	49
2	Ballari	0	3	28	31
3	Belagavi	0	42	12	54
4	Bengaluru Rural	0	1	5	6
5	Bengaluru Urban	0	0	0	0
6	Bidar	0	0	0	0
7	Chamarajanagar	0	0	0	0
8	Chikkaballapura	0	16	38	54
9	Chikkamagaluru	0	0	0	0
10	Chitradurga	0	63	59	122
11	Dakshina Kannada	0	0	0	0
12	Davanagere	0	24	9	33
13	Dharwad	0	0	0	0
14	Gadag	0	6	2	8
15	Hassan	0	0	1	1
16	Haveri	0	0	13	13
17	Kalaburagi	0	0	0	0
18	Kodagu	0	0	0	0
19	Kolar	2	4	24	30
20	Koppal	1	33	9	43
21	Mandya	0	0	7	7
22	Mysuru	0	0	2	2
23	Raichur	1	0	4	5
24	Ramanagara	0	0	0	0
25	Shivamogga	0	0	4	4
26	Tumakuru	15	254	29	298
27	Udupi	0	0	0	0
28	Uttara Kannada	0	0	0	0
29	Vijayapura	0	0	0	0
30	Yadgir	0	0	0	0
	Total	**19**	**495**	**246**	**760**

March to May was considered as pre-monsoon, June to November was considered as monsoon and December to February was considered as post-monsoon. The data were tabulated according to different seasons to know the distribution pattern of Bluetongue disease outbreak during the period 2005-2019. Season-wise distribution of Bluetongue disease outbreak among Sheep and Goats is presented in Table 4.4 and Fig. 4.4. Data indicates that the highest outbreak of Bluetongue disease during monsoon (254) and pre-monsoon (19) was observed in Tumakuru district whereas it was highest in Chitradurga during post-monsoon period. However, the sum of the outbreaks of Bluetongue disease in three seasons was highest in Tumakuru district (298) followed by Chitradurga (122), Belagavi (54) and Chikkaballapura (54).

There is no pattern observed in outbreak of Bluetongue disease outbreak among Sheep and Goats from season to season and the variation may be irregular due to fact that the factors favouring the disease outbreak are different in each season in each district.

4.1.2 Outbreak in three time periods

Data pertaining to 15 years study period, *i.e.,* 2005-2019 was divided into three time periods *viz.,* from 2005 to 2009, 2010 to 2014 and from 2015 to 2019 so as to understand the pattern in the Bluetongue disease outbreaks in different time periods in each district.

(a) District-wise

Data were analysed and district-wise distribution of Bluetongue disease outbreak among Sheep and Goats in three time periods and the results are presented in Table 4.5 and Fig.4.5. Data during the first period, *i.e.,* 2005 to 2009 reveals that the total number of outbreaks reported was 544 of which the highest number of outbreaks was found to be in Tumakuru district (267), followed by Chitradurga (86), Belagavi (86), Bagalakote (47), Kolar (24), Davanagere (23), Koppal (18), Haveri (7), Gadag (5), Mandya (5), Ballari (5), Shivamogga (2), Bengaluru rural (1), Mysuru (1) and Raichur (1). There was no reporting of the disease outbreak in the rest of the districts.

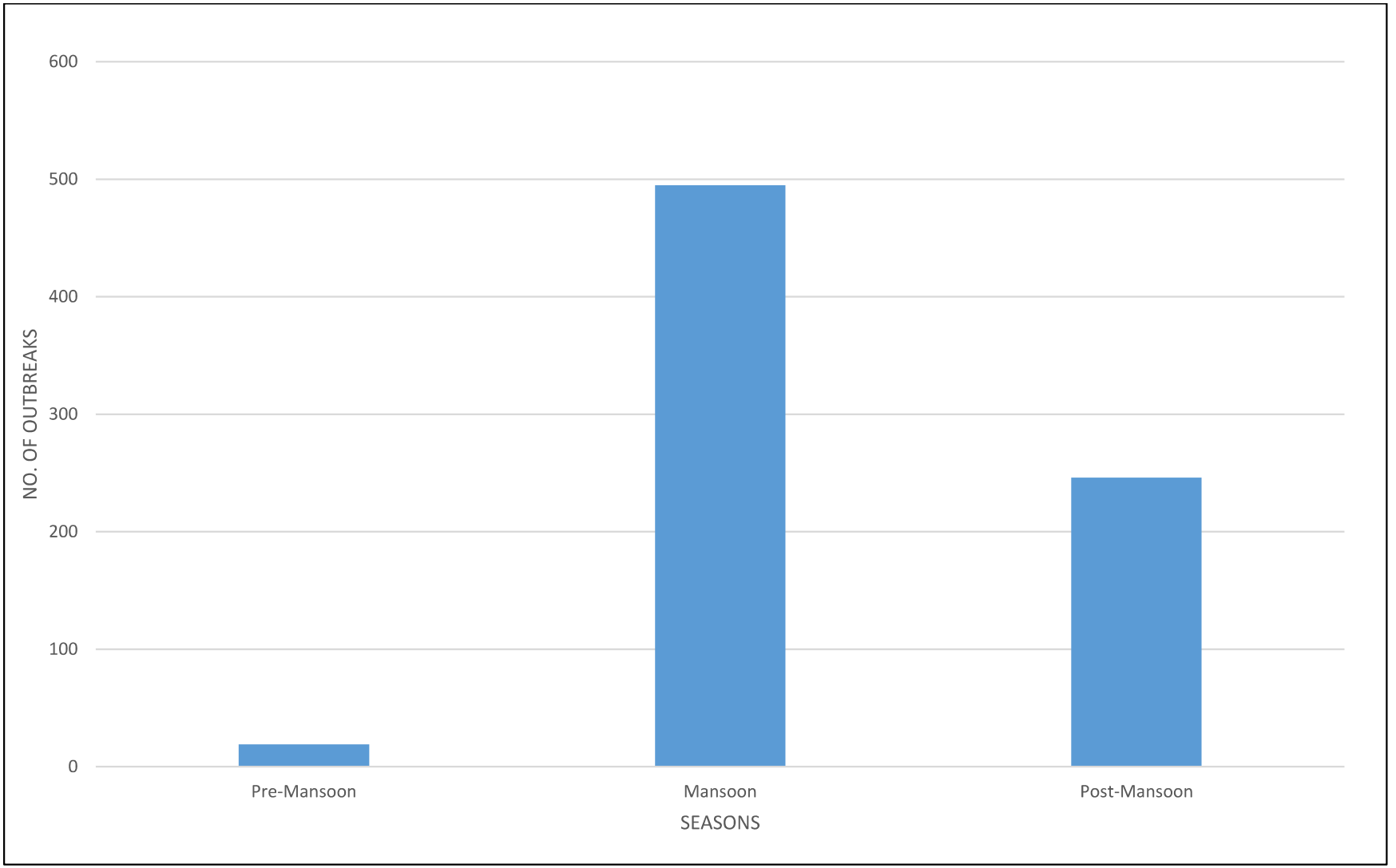

Fig. 4.4: Season-wise distribution of Bluetongue disease outbreak among Sheep and Goats (2006-2017)

Table 4.5: District-wise distribution of Bluetongue disease outbreak among Sheep and Goats in three time periods

Sl. No.	District	Bluetongue disease outbreak among Sheep and Goats		
		2005-2009	2010-2014	2015-2019
		Number	Number	Number
1	Bagalakote	47	2	0
2	Ballari	3	0	28
3	Belagavi	54	0	0
4	Bengaluru Rural	1	2	3
5	Bengaluru Urban	0	0	0
6	Bidar	0	0	0
7	Chamarajanagar	0	0	0
8	Chikkaballapura	0	27	27
9	Chikkamagaluru	0	0	0
10	Chitradurga	86	23	13
11	Dakshina Kannada	0	0	0
12	Davanagere	23	5	5
13	Dharwad	0	0	0
14	Gadag	5	1	2
15	Hassan	0	0	1
16	Haveri	7	1	5
17	Kalaburagi	0	0	0
18	Kodagu	0	0	0
19	Kolar	24	0	6
20	Koppal	18	13	12
21	Mandya	5	1	1
22	Mysuru	1	0	1
23	Raichur	1	0	4
24	Ramanagara	0	0	0
25	Shivamogga	2	0	2
26	Tumakuru	267	4	27
27	Udupi	0	0	0
28	Uttara Kannada	0	0	0
29	Vijayapura	0	0	0
30	Yadgir	0	0	0
	Total	**543**	**79**	**137**

During the second period, *i.e.,* 2010 to 2014, data shows that the total number of outbreaks was found to be very less (79) as compared to 544 in the first period. The highest number of outbreaks were reported in Chikkaballapura (27) followed by Chitradurga (23), Koppal (13), Davanagere (5), Tumakuru (4), Bagalakote (2), Bengaluru rural (2), Gadag (1), Haveri (1) and Mandya (1). The disease outbreak was not found in rest of the districts but some of them had reported the disease outbreak in the first period.

During the third period, *i.e.,* 2015 to 2019, data shows that the total number of outbreaks was found to be 137 which was as compared to second period (79) and less as compared to first period (544). The highest number of outbreaks were reported in Ballari (28) followed by Chikkaballapura (27), Tumakuru (27), Chitradurga (13), Koppal (12), Kolar (6), Davanagere (5), Haveri (5), Raichur (4), Bengaluru rural (3), Gadag (2), Shivamogga (2), Hassan (1), Mandya (1) and Mysuru (1). The disease outbreak was not found in the rest of the districts but some of them had reported the disease outbreak in the first and second periods.

The variation in disease outbreaks in the three periods may be due to the fact that the different prevailing factors during those periods in each district.

(b) Season-wise

Data were analyzed and season wise comparison of Bluetongue disease outbreak among Sheep and Goats in three time periods is presented in Table 4.6 and Fig.4.6. Data during the first period (2005-2009) shows that the highest Bluetongue disease outbreak was reported in monsoon season (429) followed by post-monsoon (103) and pre-monsoon (12). During the second period (2010-2014) reveals that the highest Bluetongue disease outbreak was reported in post-monsoon (54) followed by monsoon season (25) and no outbreak was found in pre-monsoon season. During the third period (2015-2019) reveals that the highest Bluetongue disease outbreak was reported in post-monsoon (89) followed by monsoon season (41) and pre-monsoon (7).

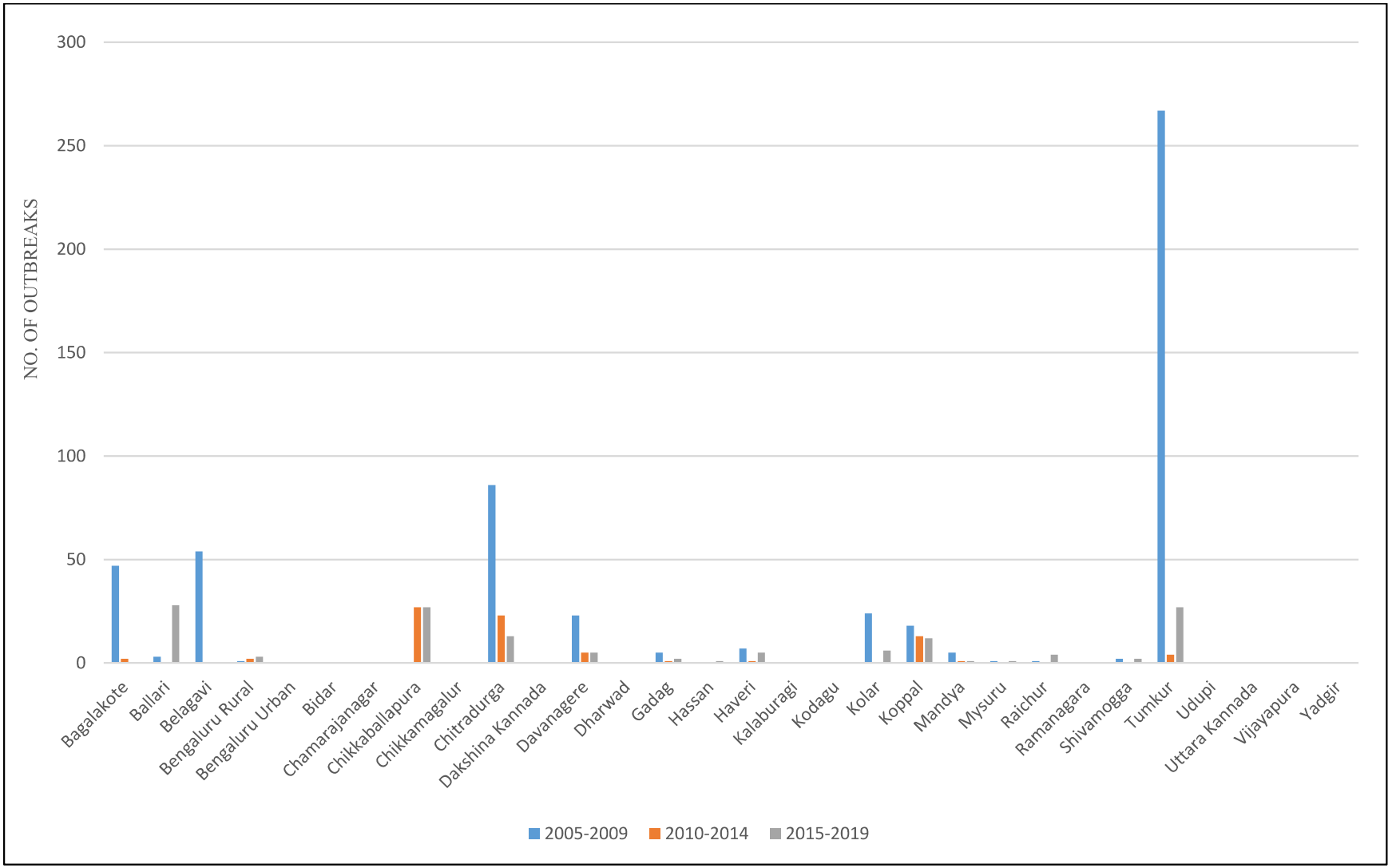

Fig. 4.5: District wise distribution of Bluetongue disease outbreak among Sheep and Goats in three time periods

Table 4.6: Season-wise distribution of Bluetongue disease outbreak among Sheep and Goats in three time periods

Sl. No.	District	Bluetongue disease outbreak among Sheep and Goats								
		Pre-Monsoon			Monsoon			Post-Monsoon		
		2005-2009	2010-2014	2015-2019	2005-2009	2010-2014	2015-2019	2005-2009	2010-2014	2015-2019
1	Bagalakote	0	0	0	47	2	0	0	0	0
2	Ballari	0	0	0	2	0	1	1	0	27
3	Belagavi	0	0	0	42	0	0	12	0	0
4	Bengaluru Rural	0	0	0	0	0	1	1	2	2
5	Bengaluru Urban	0	0	0	0	0	0	0	0	0
6	Bidar	0	0	0	0	0	0	0	0	0
7	Chamarajanagar	0	0	0	0	0	0	0	0	0
8	Chikkaballapura	0	0	0	0	0	16	0	27	11
9	Chikkamagaluru	0	0	0	0	0	0	0	0	0
10	Chitradurga	0	0	0	54	8	1	32	15	12
11	Dakshina Kannada	0	0	0	0	0	0	0	0	0
12	Davanagere	0	0	0	23	1	0	0	4	5
13	Dharwad	0	0	0	0	0	0	0	0	0
14	Gadag	0	0	0	5	1	0	0	0	2
15	Hassan	0	0	0	0	0	0	0	0	1
16	Haveri	0	0	0	0	0	0	7	1	5
17	Kalaburagi	0	0	0	0	0	0	0	0	0
18	Kodagu	0	0	0	0	0	0	0	0	0
19	Kolar	0	0	2	4	0	0	20	0	4
20	Koppal	0	0	1	17	11	5	1	2	6
21	Mandya	0	0	0	0	0	0	5	1	1
22	Mysuru	0	0	0	0	0	0	1	0	1
23	Raichur	1	0	0	0	0	0	0	0	4
24	Ramanagara	0	0	0	0	0	0	0	0	0
25	Shivamogga	0	0	0	0	0	0	2	0	2
26	Tumakuru	11	0	4	235	2	17	21	2	6
27	Udupi	0	0	0	0	0	0	0	0	0
28	Uttara Kannada	0	0	0	0	0	0	0	0	0
29	Vijayapura	0	0	0	0	0	0	0	0	0
30	Yadgir	0	0	0	0	0	0	0	0	0
	Total	**12**	**0**	**7**	**429**	**25**	**41**	**103**	**54**	**89**

During pre-monsoon season, Tumakuru was found to have the highest disease outbreak (11) in first period followed by Raichur (1). No outbreak was found in case of second period. Whereas in third time period Tumakuru was found to have the highest disease outbreak (4) followed by Kolar (2) and Koppal (1).

During the monsoon season, Tumakuru district was found to have the highest number of outbreaks (235) followed by Chitradurga (54), Bagalakote (47), Belagavi (32), Davanagere (23), Koppal (17), Gadag (5), Kolar (4), and Ballari (2) in first period. In second period Koppal was found to have high outbreaks (11) followed by Chitradurga (8), Bagalakote, Tumakuru (2 each) and Davanagere, Gadag (1 each). Whereas in third time period the number of outbreaks was highest in Tumakuru (17) followed by Chikkaballapura (16), Koppal (5) and Bengaluru rural, Ballari, Chitradurga (1 each).

During post-monsoon season, Chitradurga had the highest number of outbreaks (32) followed by Tumakuru (21), Kolar (20), Belagavi (12), Haveri (7), Mandya (5), Shivamogga (2) and Bengaluru, Ballari, Koppal, Mysuru, Raichur (1 each) in first period. In second time period the number of outbreaks was highest in Chikkaballapura (27) followed by Chitradurga (7), Davanagere (4), Bengaluru rural, Koppal, Tumakuru (2 each) and one outbreak in Haveri and Mandya. Whereas in third time period the number of outbreaks was highest in Ballari (27) followed by Chitradurga (12), Chikkaballapura (11), Koppal, Tumakuru (6 each), Davanagere, Haveri (5 each), Kolar, Raichur (4 each), Bengaluru rural, Gadag, Shivamogga (2 each) and Hassan, Mandya, Mysuru (1 each).

The variation in outbreaks of disease from period to period and season to season may be due to the fact that the favorable existing factors in each district.

(c) Month-wise

Data were analyzed month-wise distribution of Bluetongue disease outbreak among Sheep and Goats in three time periods and the results are presented in Table 4.7 and Fig. 4.7. Data during the first time period (2005-2019), reveals that the highest Bluetongue disease outbreak was reported in November (356) followed by December (62), October (61) and January (33). Data during Second time period (2010-2014), it was maximum in

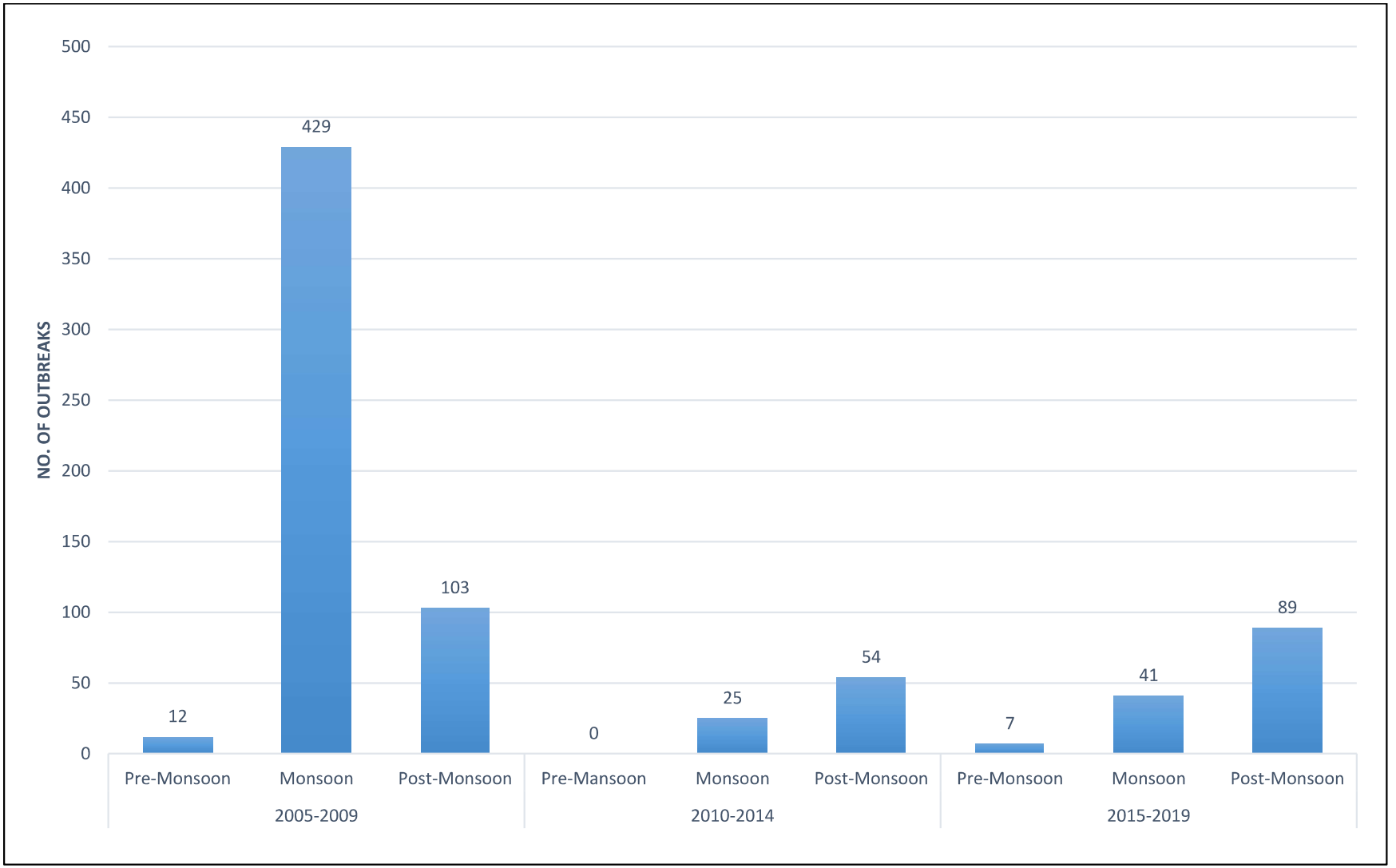

Fig. 4.6: Season-wise distribution of Bluetongue disease outbreak among Sheep and Goats in three time periods

the month of December (23) followed by January (20), November (16) and February (11). During third time period (2015-2019), the highest outbreaks were found in January (48) followed by February (22), December (19) and November (17).

In total, the occurrence of disease outbreak during third time period increased in most of the months as compared to first and second time period. This may be due to the fact that the favorable existing factors in each month in each time period.

4.2 Assessing and estimating the risk of Bluetongue disease outbreak among Sheep and Goats

Adopted statistical tools like spatial autocorrelation and space-time cluster analysis to detect the endemicity, correlation and cluster of Bluetongue disease outbreak among Sheep and Goats for the past 15 years (2005 to 2019) in 30 districts of Karnataka.

4.2.1 Spatial endemicity

During the study period of 15 years from 2005-2019, the data on the incidence of Bluetongue disease in Karnataka was analysed to identify the distribution of disease. Spatial endemicity of Bluetongue disease outbreak among Sheep and Goats is represented in Table 4.8 and Fig. 4.8. The data indicated that the endemic nature of disease in the study region, the very high incidence was observed in Tumakuru district (range >240), the high incidence in Chitradurga districts (range 121-180), the low incidence in Bagalakote, Ballari, Belagavi, Bengaluru Rural, Chikkaballapura, Gadag, Haveri, Kolar, Koppal, Mandya, Mysuru and Raichur district (range 1-60). The rest of the districts were not fallen in any of these spatial endemicity categories of Bluetongue disease outbreak.

Even though the occurrence of Bluetongue disease in Sheep and Goats remained as a disease that was spread across the country in all the years studied, the typical seasonal trend was observed within each year. The infection pressure was high during November and December months, with the peak noticed in the month of November in all the years. The lowest incidence of disease was observed in April and August months.

Table 4.7: Month-wise distribution of Bluetongue disease outbreak among Sheep and Goats in three time periods

Months	Bluetongue disease outbreak among Sheep and Goats					
	2005-2009		2010-2014		2015-2019	
	Outbreak	Per cent	Outbreak	Per cent	Outbreak	Per cent
January	33	6.06	20	25.32	48	35.04
February	8	1.47	11	13.92	22	16.06
March	12	2.21	0	0.00	3	2.19
April	0	0.00	0	0.00	0	0.00
May	0	0.00	0	0.00	4	2.92
June	0	0.00	0	0.00	1	0.73
July	0	0.00	2	2.53	10	7.30
August	0	0.00	0	0.00	0	0.00
September	12	2.21	0	0.00	1	0.73
October	61	11.21	7	8.86	12	8.76
November	356	65.44	16	20.26	17	12.40
December	62	11.40	23	29.11	19	13.87
Total	**544**	**100**	**79**	**100**	**137**	**100**

Table 4.8: Spatial endemicity of Bluetongue disease

District	Outbreak range	Special endemicity category
Tumakuru	>240	Very high
Chitradurga	121-180	Medium
Bagalakote, Ballari, Belagavi, Bengaluru Rural, Chikkaballapura, Gadag, Haveri, Kolar, Koppal, Mandya, Mysuru and Raichur.	1-60	Very low

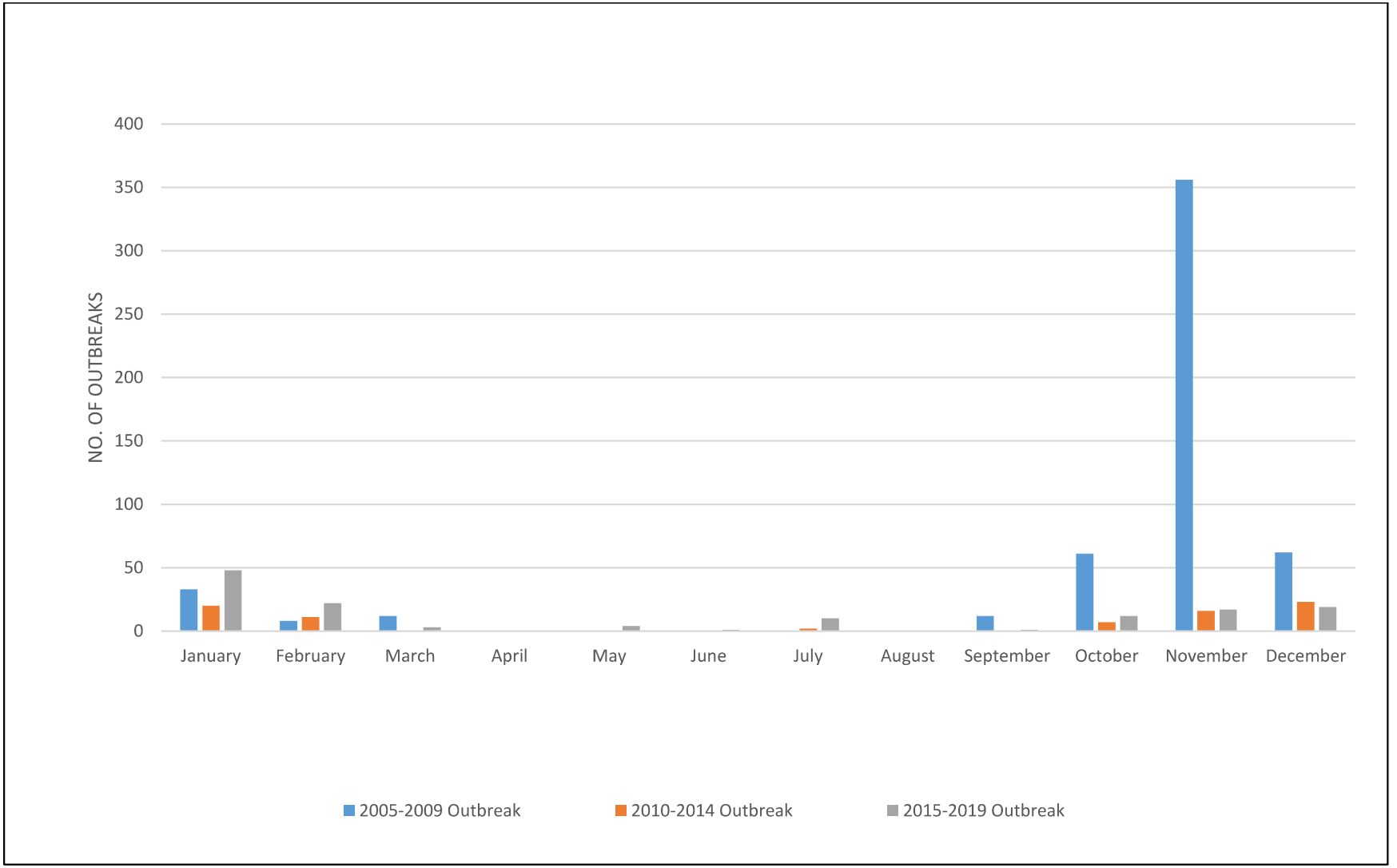

Fig. 4.7: Month-wise distribution of Bluetongue disease outbreak among Sheep and Goats in three time periods

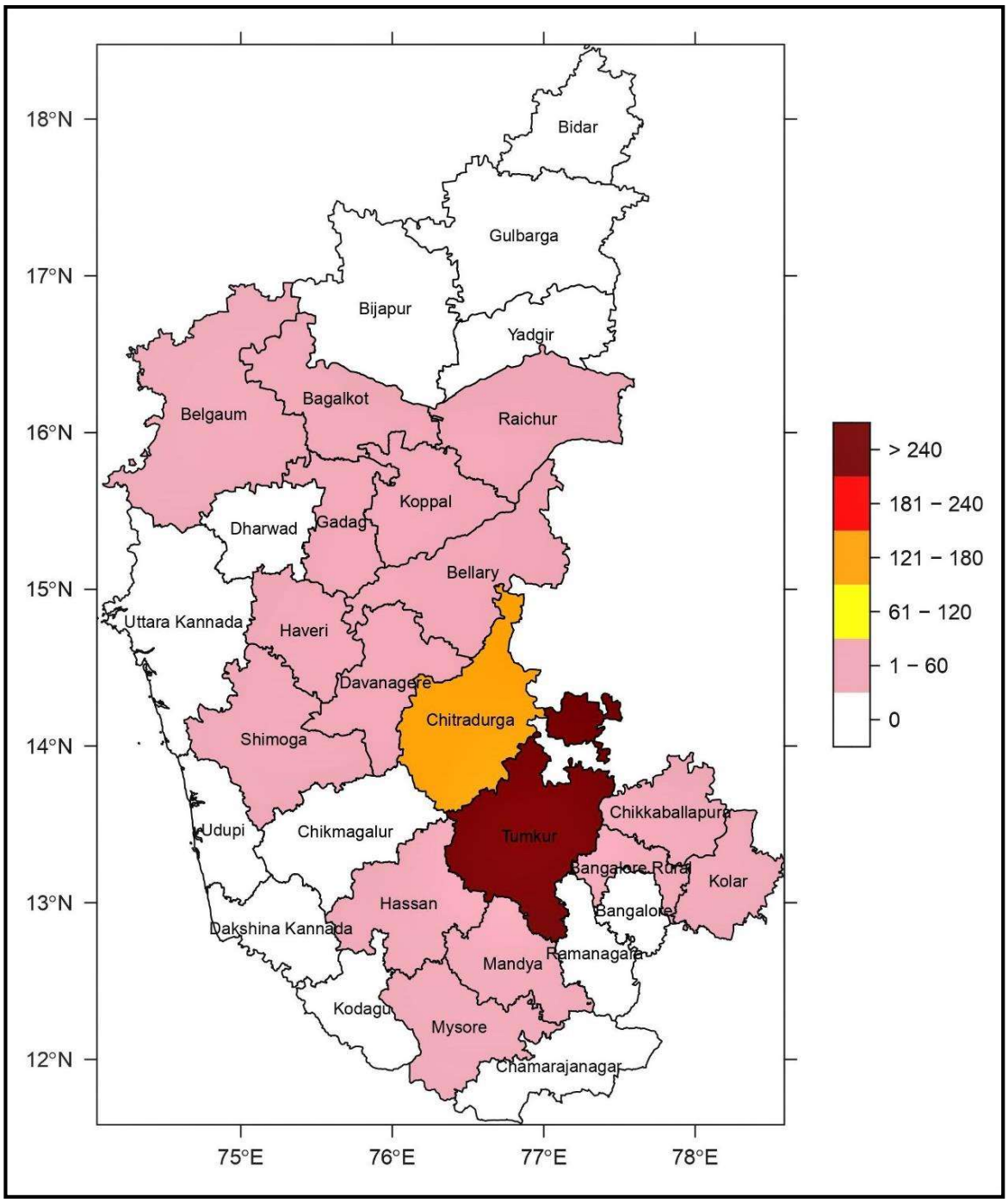

Fig. 4.8: Spatial endemicity of Bluetongue disease outbreak among Sheep and Goats

4.2.2 Spatial autocorrelation

Hotspot analysis (Getis-Ord Gi*) is the method for determining local spatial autocorrelation. A prerequisite for hotspot analysis is the presence of clusters within the dataset and gives the output value a z-score, where a high z-score is indicative of a hotspot or clusters. Accordingly, data were computed and results on spatial autocorrelation for Bluetongue disease outbreak among Sheep and Goats are represented in Table 4.9 and Fig. 4.9. The data shows that a high z-score indicate the presence of hotspots, where a negative z-score indicates a cold spot. The districts *viz.*, Koppal, Davanagere, Tumakuru, Ballari, Mandya, Bengaluru Rural, Raichur and Hassan were identified as hotspots and the rest of the districts were identified as cold spots.

The results are similar to that of the trend on FMD reported by Ma *et al*. (2017). Hence, the Getis-Ord Gi* analysis used in this study is effective for identifying the risk of disease outbreak. Therefore, it can be used for identifying districts with high risks of disease outbreak for further analysis & modelling.

4.2.3 Space-time cluster analysis

A discrete Poisson model was used after detecting the existence of a hotspot using Getis-Ord Gi* analysis, and the number of cases of Bluetongue in each location was assumed to be Poisson-distributed. When there are no covariates and the null hypothesis is true, the estimated number of cases in each field is proportional to its population size. The Poisson data was analysed with purely temporal, purely spatial, and space-time models. The probability function was maximised across all window positions and sizes, and the cluster with the highest likelihood is the most probable and the least likely to have occurred by chance.

Accordingly, data were analysed and the results on space-time cluster analysis of Bluetongue disease outbreak among Sheep and Goats are presented in Table 4.10 and Fig. 4.10. Data revealed the existence of disease clusters in the central region of Karnataka from 2005-2019.

Table 4.9: Spatial autocorrelation for Bluetongue disease outbreak among Sheep and Goats

Sl. No.	District	z-score	Category
1	Koppal	0.253	Hotspot
2	Davanagere	0.106	
3	Tumakuru	0.087	
4	Ballari	0.040	
5	Mandya	0.022	
6	Bengaluru Rural	0.010	
7	Raichur	0.010	
8	Hassan	0.004	
9	Kolar	-0.022	Cold spot
10	Chamarajanagar	-0.030	
11	Belagavi	-0.031	
12	Bidar	-0.031	
13	Udupi	-0.031	
14	Vijayapura	-0.031	
15	Bagalakote	-0.032	
16	Bengaluru Urban	-0.032	
17	Chikkaballapura	-0.032	
18	Chikkamagaluru	-0.032	
19	Chitradurga	-0.032	
20	Dakshina Kannada	-0.032	
21	Dharwad	-0.032	
22	Gadag	-0.032	
23	Haveri	-0.032	
24	Kalaburagi	-0.032	
25	Mysuru	-0.032	
26	Ramanagara	-0.032	
27	Shivamogga	-0.032	
28	Uttara Kannada	-0.032	
29	Yadgir	-0.032	
30	Kodagu	-0.033	

Table 4.10: Space-time cluster analysis for Bluetongue disease outbreak among Sheep and Goats

Sl. No.	District	Relative Risk (RR)	Radius (in km)
1	Tumakuru	11.005	0
2	Belagavi	5.352	0
3	Chitradurga, Davanagere, Gadag, Haveri, Hassan and Shivamogga.	0.253	161.45

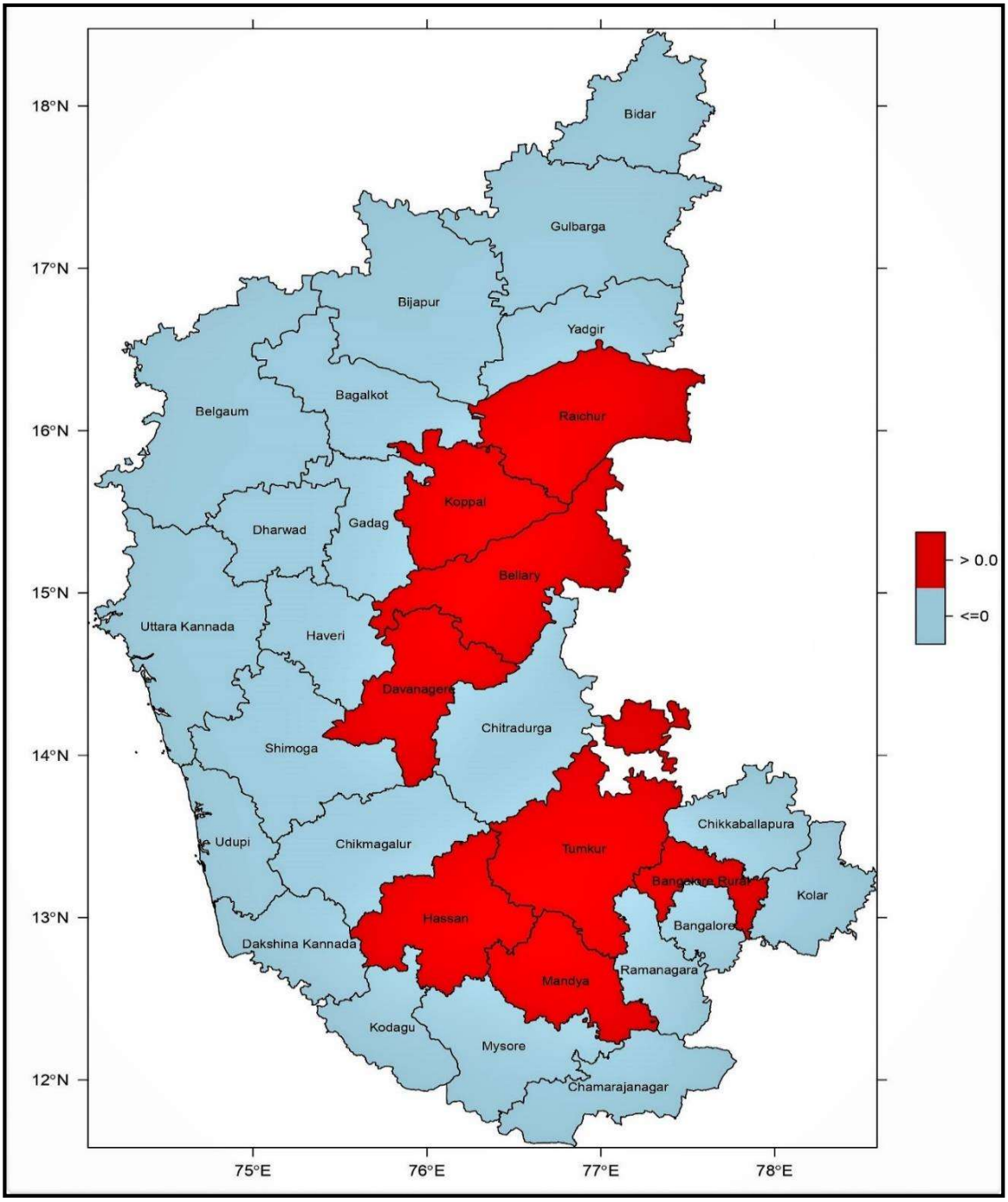

Fig. 4.9: Spatial autocorrelation for Bluetongue disease outbreak among Sheep and Goats

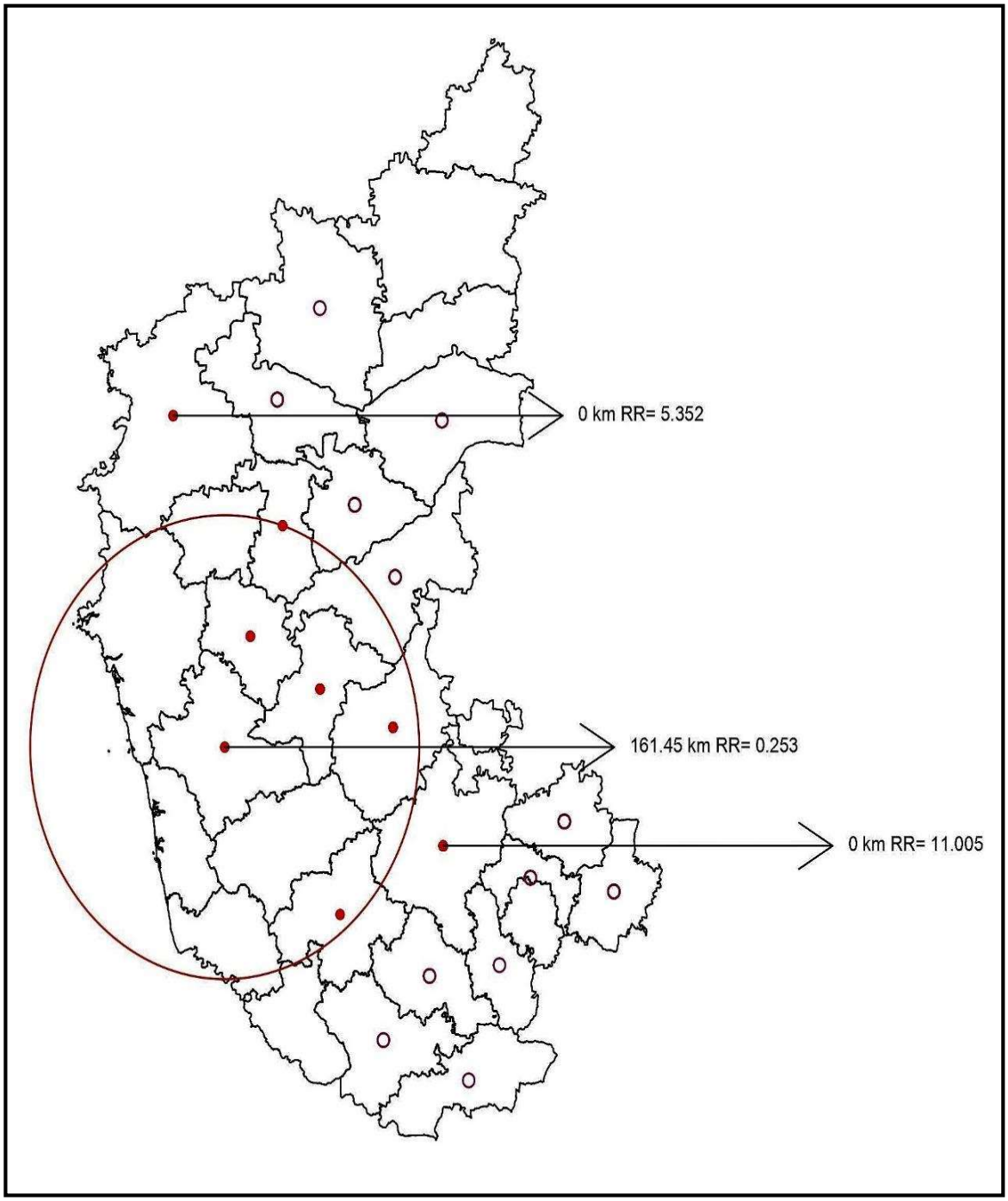

Fig. 4.10: Space time cluster analysis of Bluetongue disease outbreak among Sheep and Goats

The spatial variation indicated one significant cluster that includes Chitradurga, Davanagere, Gadag, Haveri, Hassan and Shivamogga of relative risk (RR=0.253) at 161.45km of radius that was contributing to an increasing pattern in Bluetongue disease outbreak among Sheep and Goats. During the period of 2005 to 2019, the district level disease clustering was identified i.e. Belagavi and Tumakuru district (5.352 RR and 11.005 RR respectively) disease incidence was represented by red colour dots within the significant red circles. This indicates the district with a high risk of disease incidence, while a pink circle dot *viz*., Bagalakote, Ballari, Bengaluru rural, Chamarajanagar, Chikkaballapura, Kolar, Koppal, Mandya, Mysuru, Raichur, Ramanagara and Vijayapura represents districts having disease incidence but are not part of significant clusters. The results are on par with the trend of relative risk on FMD as reported by Lee *et al*. (2020). Hence the space-time cluster analysis adopted for the study of relative risk on Bluetongue disease outbreak among Sheep and Goats is effective.

4.3 Climatic risk factors associated with Bluetongue disease outbreak among Sheep and Goats

Identification of significant disease clusters using Space-time cluster model prompted in the study to identify the climatic risk variables responsible for the significant cluster formation. Therefore, in this step, an attempt was made to use the Linear Discriminant Analysis (LDA) to determine significant risk factors (climatic and remote sensing) responsible for the formation of disease clusters at district level. The identified risk parameters were further utilized for spatial risk modelling and prediction. The LDA results on climatic risk factors associated with Bluetongue outbreak among Sheep and Goats are presented in Table 4.11. Environmental factors that were found to be significantly related with the disease incidence at *P*-value ≤ 0.05 were considered for disease risk modelling. Data indicated the potential risk factor as rainfall. The significant clusters were superimposed over the major significant risk parameters which is positively influenced the disease incidence. The results are in similar to that the trend of risk factors associated with coronary artery disease as reported by Ricciardi *et al*. (2020). Thus, LDA tool used for identifying the climatic risk factors associated with Bluetongue outbreak among Sheep and Goats is effective.

Table 4.11: Climatic risk factors associated with outbreak of Bluetongue disease outbreak among Sheep and Goats

Climatic risk factors	DF	SS	MSS	F-value	*p*-value
Air temperature	1	0.36	0.36	1.40	0.24^{NS}
Cloud cover	1	0.80	0.80	3.12	0.08^{NS}
EVI	1	0.01	0.01	0.04	0.86^{NS}
LAI	1	0.16	0.16	0.62	0.43^{NS}
LST	1	0.09	0.09	0.35	0.55^{NS}
NDVI	1	0.03	0.03	0.11	0.74^{NS}
PET	1	0.11	0.11	0.44	0.51^{NS}
Potential evaporation rate	1	0.41	0.41	1.60	0.21^{NS}
Precipitation	1	0.04	0.04	0.17	0.68^{NS}
Rainfall	1	1.41	1.41	5.55	0.02*
Soil moisture	1	0.09	0.09	0.35	0.55^{NS}
Specific humidity	1	0.06	0.06	0.25	0.62^{NS}
Surface pressure	1	0.01	0.01	0.07	0.90^{NS}
Temperature	1	0.01	0.01	0.01	0.97^{NS}
Maximum temperature	1	0.27	0.27	1.05	0.31^{NS}
Minimum temperature	1	0.16	0.16	0.62	0.43^{NS}
Vapour pressure	1	0.18	0.18	0.70	0.40^{NS}
Wetness	1	0.04	0.04	0.17	0.68^{NS}
Residuals	105	26.71	0.25		
Total	**123**	**30.95**			

*. Significant at 0.05 level, ^{NS} Indicate Non-Significance

4.4 Risk prediction of Bluetongue disease outbreak among Sheep and Goats

The climatic risk factors were subjected to the climate-disease modelling. Maps were generated based on affected (case) areas of Bluetongue disease.

In this study, a new statistical approach was developed for risk mapping to improve the accuracy of short-term risk prediction. The disease data were modelled with significant predictor variables identified by the LDA function, such as meteorological data and remote sensing data through ensemble machine learning models. The best-fitted models are RF & GBM. The best-fitted models were selected based on the statistically specified evaluation criteria namely Cohen's Kappa, ROC, TSS, AUC and Accuracy. The average score was calculated.

4.4.1 By using Gradient Boost Machine

Risk prediction of Bluetongue disease outbreak among Sheep and Goats was analysed by using Gradient Boosting Machine to predict the risk score for each district of Karnataka and results are presented in Table 4.12. The risk score ranges from 0 to 0.5 and risk was classified into different groups such as very high risk (>0.35), high risk (0.26-0.35), medium risk (0.16-0.25) and low or no risk (0.00-0.15). Data from Fig. 4.11 indicated that the district *viz.,* Bengaluru Rural, Bengaluru Urban, Mandya, Ramanagara, Kolar and Mysuru indicating very high risk (>0.35), Chikkaballapura, Hassan, Tumakuru, Chamarajanagar, Chikkamagaluru and Kodagu indicating high risk (0.26 to 0.35), Udupi and Uttara Kannada indicating low risk or no risk (0 to 0.15) and rest of the districts indicated as medium risk. The results are in similar to that the trend of risk prediction on Dengue fever as reported by Liu *et al*. (2014).

4.4.2 By using Random Forest

Risk prediction of Bluetongue disease outbreak among Sheep and Goats was analysed by using Random Forest to predict the risk score for each district of Karnataka and results are presented in Table 4.13. The risk score ranges from 0 to 0.8 and risk was classified into different groups such as very high risk (>0.60), high risk (0.41-0.60), medium risk (0.21-0.40) and low or no risk (0.00-0.20).

Table 4.12: Risk prediction of Bluetongue disease outbreak among Sheep and Goats by using Gradient Boost Machine

Sl. No.	District	GBM risk score	Risk range	Risk level
1	Bengaluru Rural	0.40	>0.35	Very high
2	Bengaluru Urban	0.39		
3	Mandya	0.37		
4	Ramanagara	0.37		
5	Kolar	0.36		
6	Mysuru	0.36		
7	Chikkaballapura	0.35	0.26 to 0.35	High
8	Hassan	0.35		
9	Tumakuru	0.35		
10	Chamarajanagar	0.33		
11	Chikkamagaluru	0.28		
12	Kodagu	0.27		
13	Chitradurga	0.25	0.16 to 0.25	Medium
14	Belagavi	0.24		
15	Vijayapura	0.23		
16	Gadag	0.22		
17	Bagalakote	0.21		
18	Koppal	0.21		
19	Raichur	0.21		
20	Bidar	0.20		
21	Yadgir	0.20		
22	Ballari	0.19		
23	Davanagere	0.19		
24	Dharwad	0.19		
25	Kalaburagi	0.19		
26	Shivamogga	0.19		
27	Haveri	0.18		
28	Dakshina Kannada	0.16		
29	Udupi	0.12	0.00 to 0.15	Low
30	Uttara Kannada	0.11		

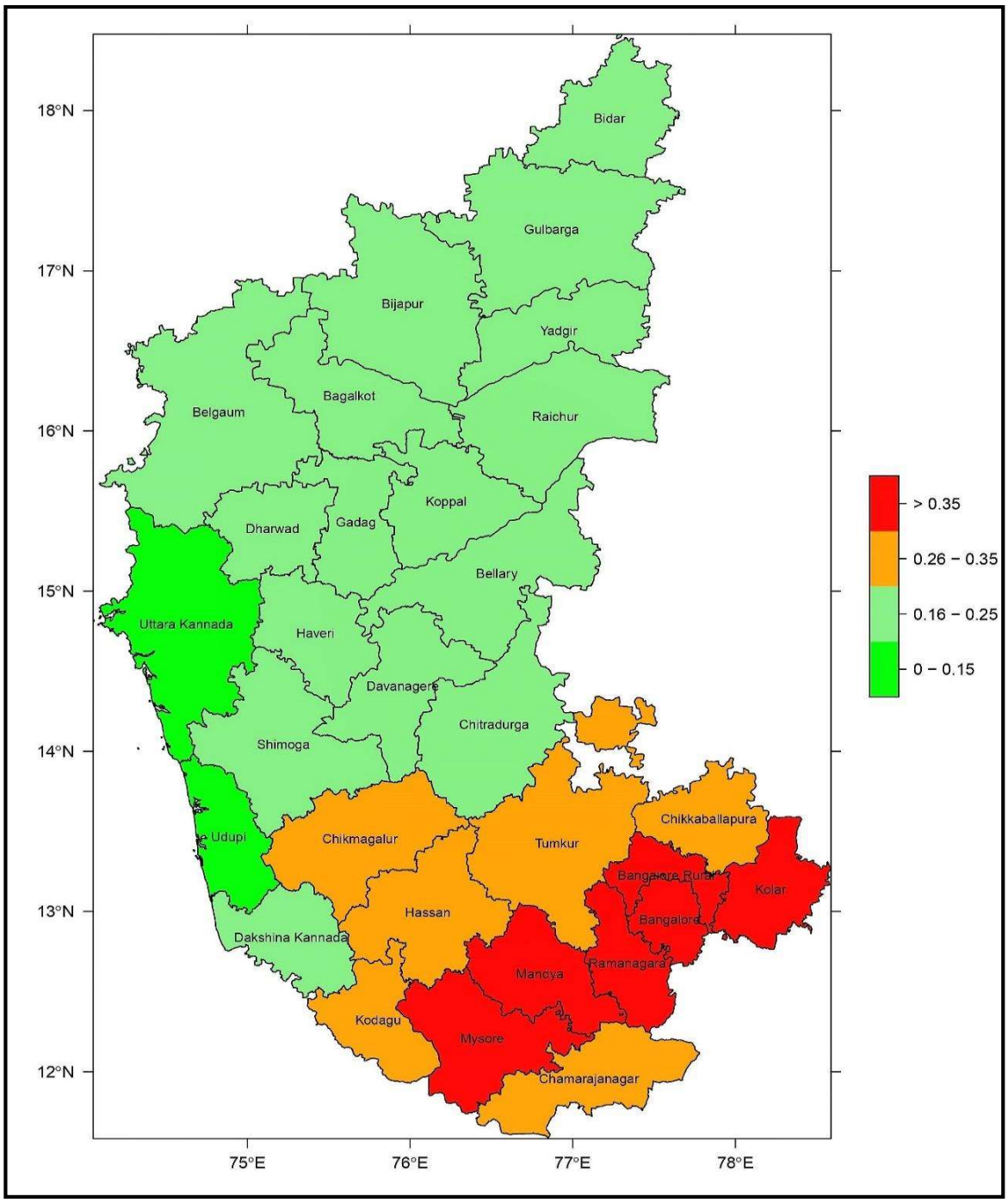

Fig. 4.11: Risk prediction of Bluetongue disease outbreak among Sheep and Goats by using Gradient Boost Machine

Table 4.13: Risk prediction of Bluetongue disease outbreak among Sheep and Goats by using Random Forest

Sl. No.	District	RF risk score	Risk range	Risk level
1	Mysuru	0.73	>0.60	Very high
2	Yadgir	0.71		
3	Mandya	0.69		
4	Bengaluru Rural	0.62		
5	Ramanagara	0.61		
6	Chamarajanagar	0.60	0.41 to 0.60	High
7	Hassan	0.60		
8	Bidar	0.58		
9	Vijayapura	0.58		
10	Kolar	0.54		
11	Bagalakote	0.52		
12	Raichur	0.52		
13	Tumakuru	0.51		
14	Chikkaballapura	0.41		
15	Kalaburagi	0.40	0.21 to 0.40	Medium
16	Belagavi	0.34		
17	Bengaluru Urban	0.32		
18	Ballari	0.29		
19	Gadag	0.28		
20	Chitradurga	0.21		
21	Haveri	0.21		
22	Koppal	0.2	0.00 to 0.20	Low
23	Chikkamagaluru	0.17		
24	Davanagere	0.15		
25	Dharwad	0.15		
26	Shivamogga	0.12		
27	Kodagu	0.10		
28	Dakshina Kannada	0.07		
29	Udupi	0.03		
30	Uttara Kannada	0.03		

Data from Fig. 4.12 indicated that the district *viz.,* Mysuru, Yadgir, Mandya, Bengaluru Rural and Ramanagara were at very high risk (>0.6), Chamarajanagar, Hassan, Bidar, Vijayapura, Kolar, Bagalakote, Raichur, Tumakuru and Chikkaballapura indicating high risk (0.41 to 0.60), Kalaburagi, Belagavi, Bengaluru Urban, Ballari, Gadag, Chitradurga and Haveri indicating medium risk (0.21 to 0.40) and rest of the districts were in low risk or no risk. The results obtained were in concordance with Almayyan *et al*. (2016) wherein Random Forest technique was effective.

4.4.3 By using Multiple Adaptive Regression Splines

Risk prediction of Bluetongue disease outbreak among Sheep and Goats was analysed by using Multiple Adaptive Regression Splines, to predict the risk score for each district of Karnataka and results are presented in Table 4.14. The risk score ranges from 0 to 0.5 and risk was classified into different groups such as very high risk (>0.36), high risk (0.25-0.36), medium risk (0.13-0.24) and low or no risk (0.00-0.12). Data from Fig. 4.13 indicated that the district *viz.,* Bengaluru Rural, Bidar, Yadgir, Kolar, Ramanagara, Bengaluru Urban, Mandya, Tumakuru, Vijayapura, Chikkaballapura, Hassan, Dharwad and Raichur indicating the very high risk (>0.36), Kalaburagi, Chikkamagaluru, Mysuru, Bagalakote and Belagavi indicating high risk (0.25 to 0.36), Chamarajanagar, Shivamogga, Gadag, Ballari, Chitradurga, Davanagere, Haveri and Koppal indicating medium risk (0.13 to 0.24) and rest of the districts were in low risk or no risk. This result was in conformity with the findings of Senthilkumar and Poulraj (2013).

4.4.4 By using Naïve Bayes

Risk prediction of Bluetongue disease outbreak among Sheep and Goats was analysed by using Naïve Bayes, to predict the risk score for each district of Karnataka and results are presented in Table 4.15. The risk score ranges from 0.0 to 1.0 and risk was classified into different groups such as very high risk (>0.90), high risk (0.81-0.90), medium risk (0.61-0.80) and low or no risk (0.00-0.60). Data from Fig. 4.14 indicated that the district *viz.,* Dakshina Kannada and Uttara Kannada indicating the very high risk (>0.90), Kodagu, Udupi, Ballari, Koppal and Shivamogga indicating high risk (0.81 to 0.90), Vijayapura, Bengaluru Urban, Bidar, Tumakuru, Bengaluru Rural, Chikkaballapura and Kolar indicating low risk or no risk and rest of the districts indicating medium risk.

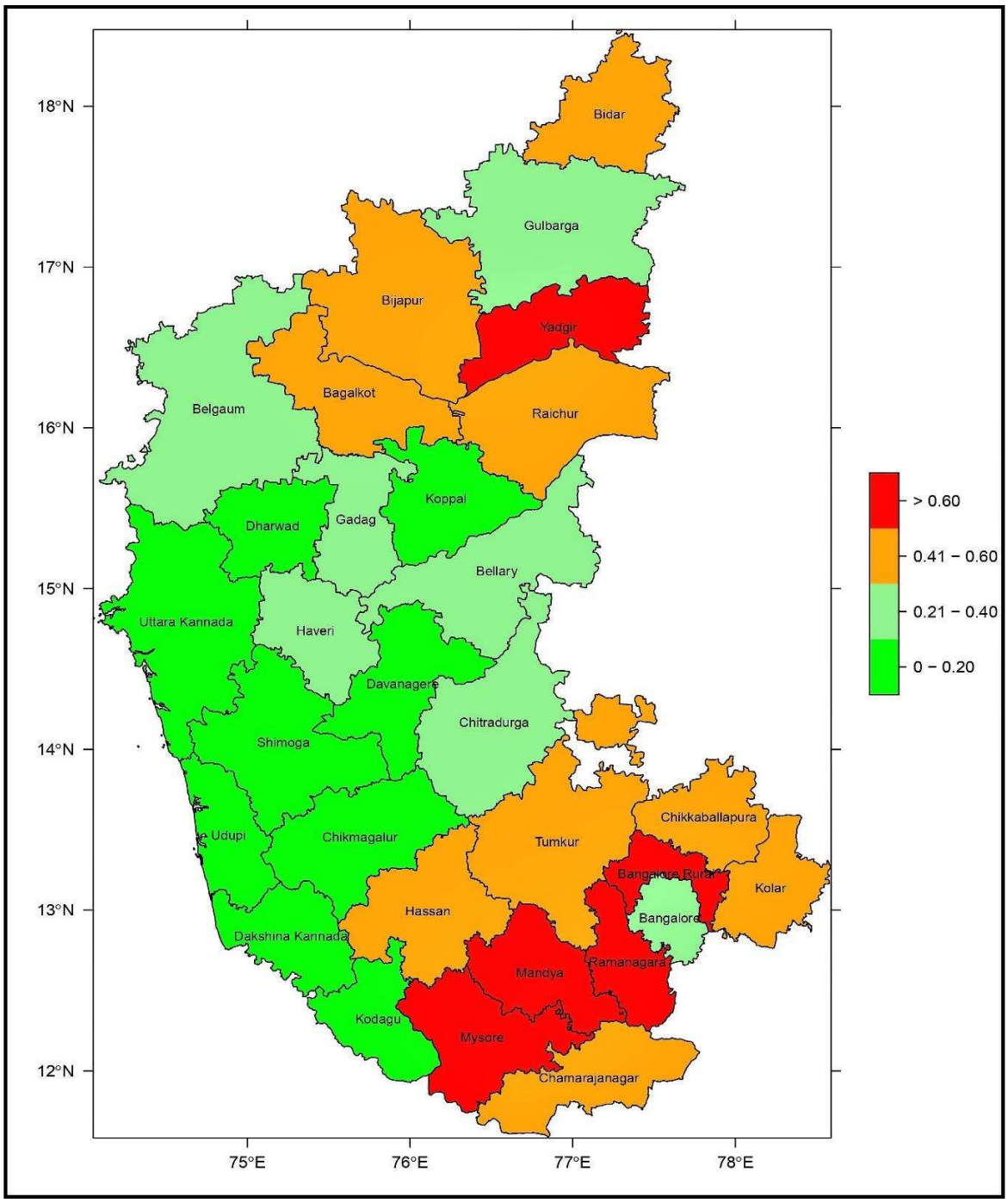

Fig. 4.12: Risk prediction of Bluetongue disease outbreak among Sheep and Goats by using Random Forest

Table 4.14: Risk prediction of Bluetongue disease outbreak among Sheep and Goats by using Multiple Adaptive Regression Splines

Sl. No.	District	MARS risk score	Risk range	Risk level
1	Bengaluru Rural	0.46	>0.36	Very high
2	Bidar	0.45		
3	Yadgir	0.45		
4	Kolar	0.44		
5	Ramanagara	0.44		
6	Bengaluru Urban	0.43		
7	Mandya	0.43		
8	Tumakuru	0.43		
9	Vijayapura	0.43		
10	Chikkaballapura	0.42		
11	Hassan	0.38		
12	Dharwad	0.37		
13	Raichur	0.37		
14	Kalaburagi	0.34	0.25 to 0.36	High
15	Chikkamagaluru	0.33		
16	Mysuru	0.31		
17	Bagalakote	0.27		
18	Belagavi	0.26		
19	Chamarajanagar	0.22	0.13 to 0.24	Medium
20	Shivamogga	0.19		
21	Gadag	0.18		
22	Ballari	0.17		
23	Chitradurga	0.17		
24	Davanagere	0.17		
25	Haveri	0.17		
26	Koppal	0.17		
27	Kodagu	0.12	0.00 to 0.12	Low
28	Dakshina Kannada	0.08		
29	Uttara Kannada	0.06		
30	Udupi	0.02		

Table 4.15: Risk prediction of Bluetongue disease outbreak among Sheep and Goats by using Naïve Bayes

Sl. No.	District	NB risk score	Risk range	Risk level
1	Dakshina Kannada	0.91	>0.90	Very high
2	Uttara Kannada	0.91		
3	Kodagu	0.89	0.81 to 0.90	High
4	Udupi	0.88		
5	Ballari	0.84		
6	Koppal	0.84		
7	Shivamogga	0.81		
8	Chamarajanagar	0.80	0.61 to 0.80	Medium
9	Chitradurga	0.78		
10	Haveri	0.77		
11	Davanagere	0.74		
12	Gadag	0.74		
13	Mysuru	0.74		
14	Belagavi	0.71		
15	Chikkamagaluru	0.71		
16	Raichur	0.7		
17	Bagalakote	0.68		
18	Dharwad	0.68		
19	Yadgir	0.68		
20	Hassan	0.66		
21	Mandya	0.65		
22	Kalaburagi	0.64		
23	Ramanagara	0.63		
24	Vijayapura	0.60	0.00 to 0.60	Low
25	Bengaluru Urban	0.58		
26	Bidar	0.56		
27	Tumakuru	0.55		
28	Bengaluru Rural	0.54		
29	Chikkaballapura	0.54		
30	Kolar	0.54		

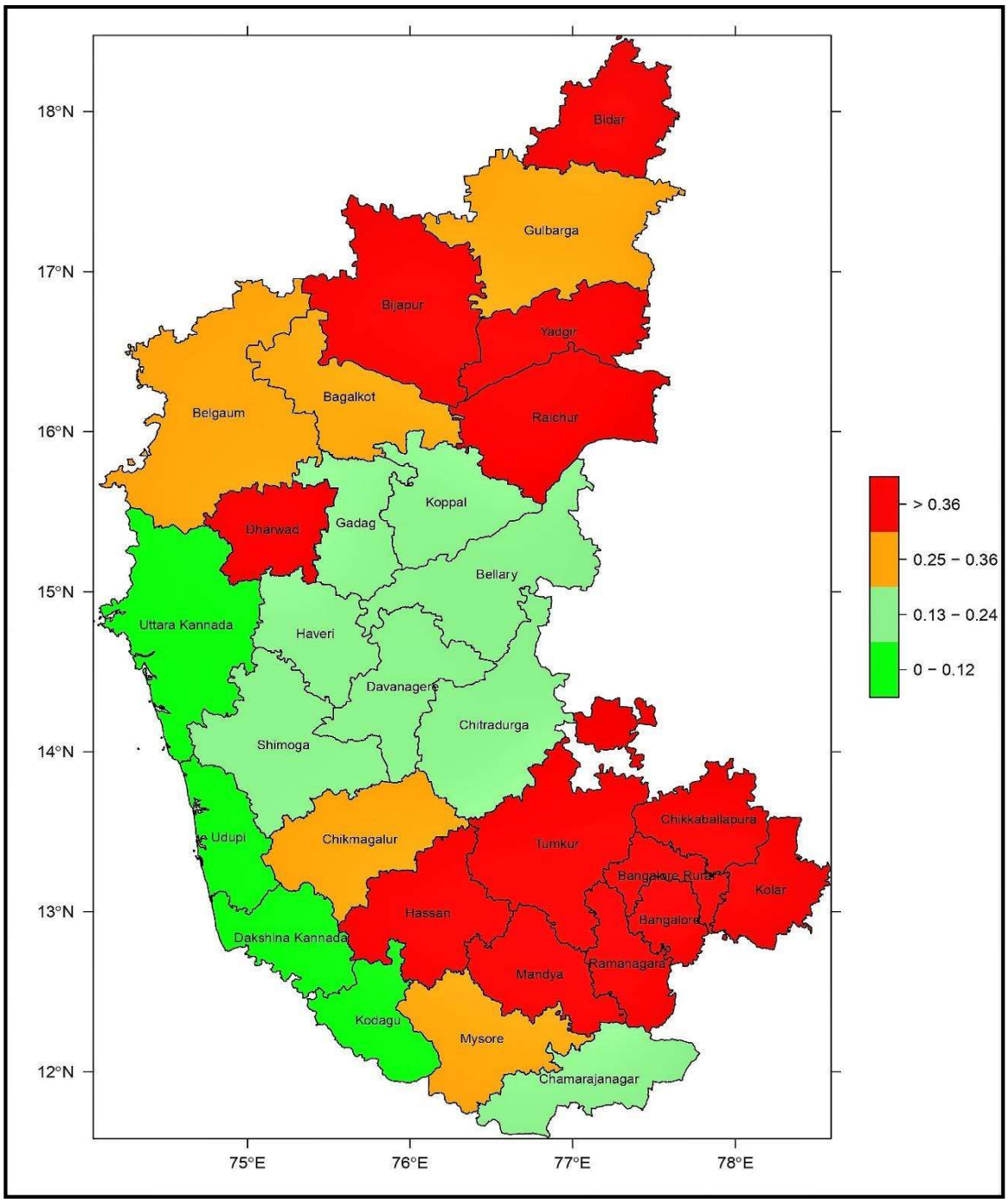

Fig. 4.13: Risk prediction of Bluetongue disease outbreak among Sheep and Goats by using Multiple Adoptive Regression Splines

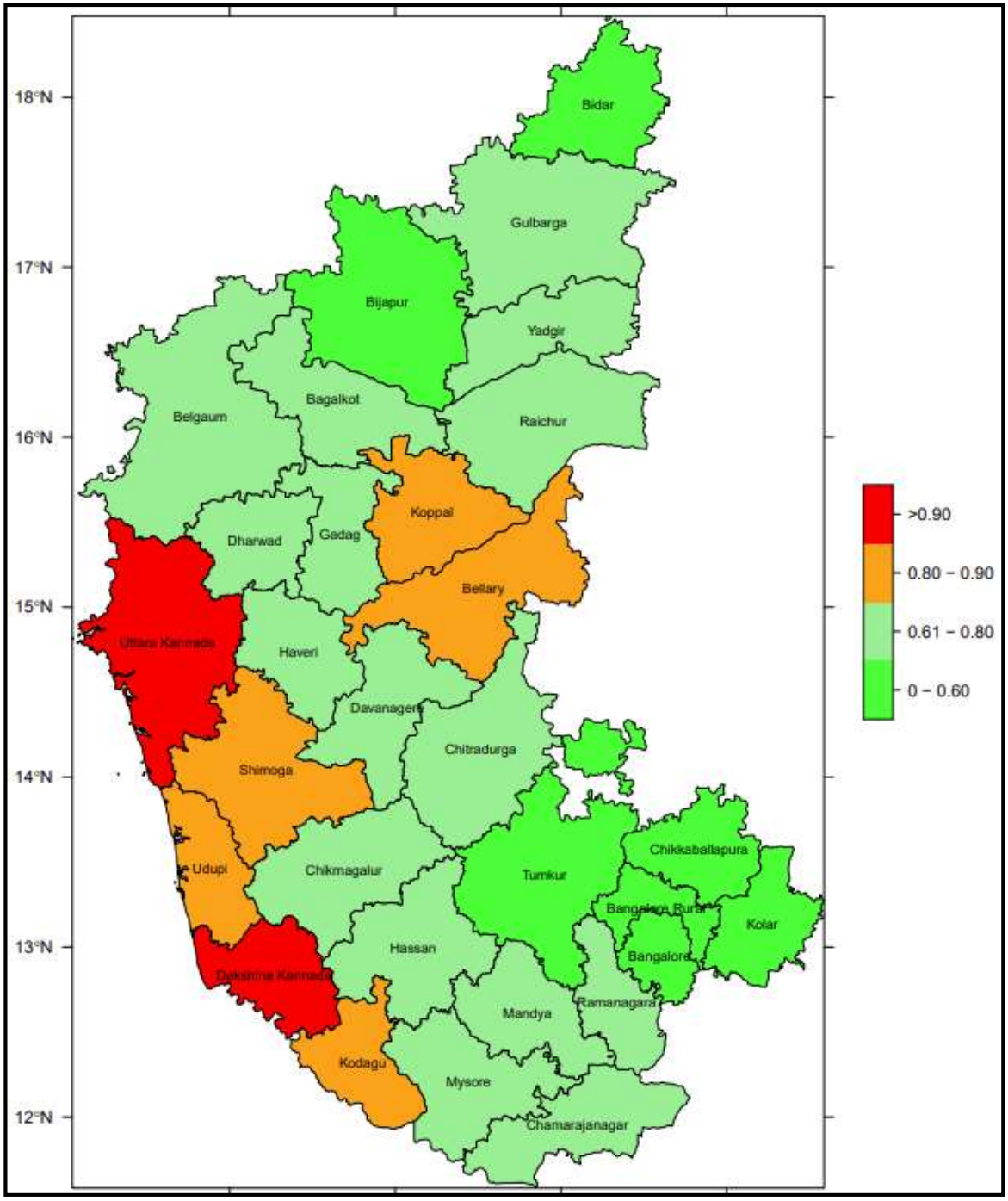

Fig. 4.14: Risk prediction of Bluetongue disease outbreak among Sheep and Goats by using Naïve Bayes

This finding is at par with the better performance of Naïve bayes classifier based on accuracy as compared to decision tree algorithm while finding the accurate count of suspects of Swine flu prediction as reported by Shinde and Pawar (2015).

4.4.5 By using Support Vector Machine

Risk prediction of Bluetongue disease outbreak among Sheep and Goats was analysed by using Support Vector Machine, to predict the risk score for each district of Karnataka and results are presented in Table 4.16. The risk score ranges from 0 to 0.20 and risk was classified into different groups such as very high risk (>0.160), high risk (0.121-0.160), medium risk (0.081-0.120) and low or no risk (0.00-0.080). Data from Fig. 4.15 indicated that the district *viz.,* Bagalakote indicating the very high risk (>0.16), Yadgir indicating medium risk (0.081 to 0.120) and the rest of the districts were in low risk or no risk. This finding is on par with the better performance of SVM based on accuracy and training time as compared to Artificial Neural Network while finding the heart disease classification and prediction as reported by Vadicherla and Sonawane (2013).

4.4.6 Model evaluation of five different machine learning models

In the present study, five machine learning models are used for disease modelling, namely Gradient Boosting Machine (GBM), Random Forest (RF), Multiple Adaptive Regression Splines (MARS), Naive Bayes (NB) and Support Vector Machine (SVM). Various modelling methods generated a variety of model artifacts, which were then used to make predictions for combinations of independent variables. To better understand and explore model predictions, response plots were developed.

The discriminating capacity of the fitted models was evaluated using Receiving Operating Characteristic (ROC) curve, Cohen's Kappa (Heildke Skill Score), True Skill Statistics (TSS), Area Under ROC Curve (AUC) and Accuracy. Rather than relying on a single best model, it recommended to use the combined prediction results of different models and averaging the score provided the best prediction. The average score was obtained by considering the model satisfying the criteria with kappa >0.40, ROC >0.80, TSS >0.50, AUC >0.80 and ACCURACY >0.70 and the resulted data on model evaluation of five different machine learning models are presented in Table 4.17.

Table 4.16: Risk prediction of Bluetongue disease outbreak among Sheep and Goats by using Support Vector Machine

Sl. No.	District	SVM risk score	Risk range	Risk level
1	Bagalakote	0.17	>0.160	Very high
2	Yadgir	0.09	0.081 to 0.120	Medium
3	Raichur	0.08	0.00 to 0.08	Low
4	Vijayapura	0.07		
5	Bidar	0.06		
6	Kalaburagi	0.06		
7	Tumakuru	0.06		
8	Belagavi	0.05		
9	Bengaluru Rural	0.05		
10	Bengaluru Urban	0.05		
11	Chamarajanagar	0.05		
12	Chikkaballapura	0.05		
13	Chikkamagaluru	0.05		
14	Dharwad	0.05		
15	Hassan	0.05		
16	Koppal	0.05		
17	Mandya	0.05		
18	Mysuru	0.05		
19	Ballari	0.04		
20	Chitradurga	0.04		
21	Dakshina Kannada	0.04		
22	Davanagere	0.04		
23	Gadag	0.04		
24	Haveri	0.04		
25	Kodagu	0.04		
26	Kolar	0.04		
27	Ramanagara	0.04		
28	Shivamogga	0.04		
29	Udupi	0.04		
30	Uttara Kannada	0.04		

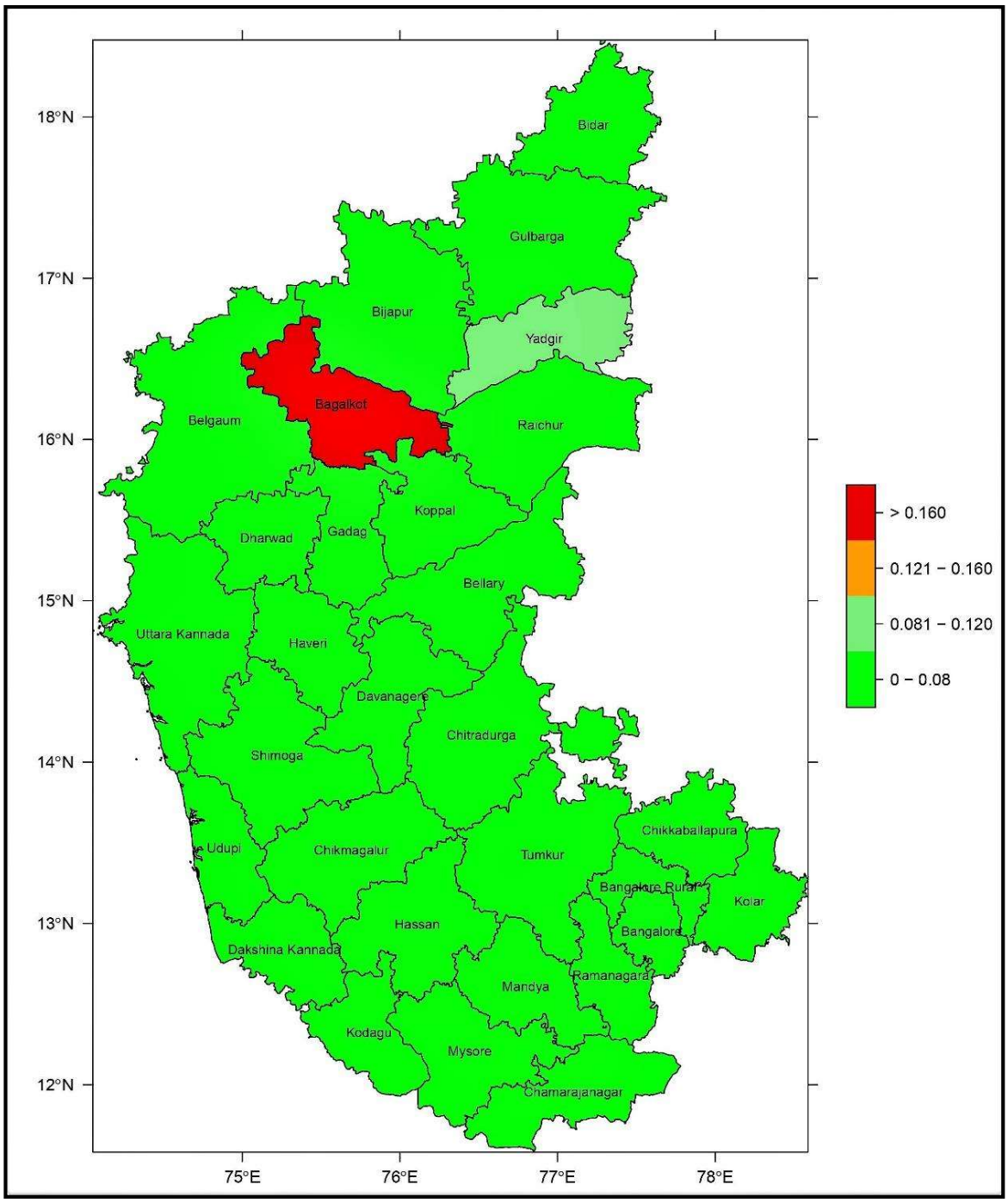

Fig. 4.15: Risk prediction of Bluetongue disease outbreak among Sheep and Goats by using Support Vector Machine

The best-fitted models were selected based on the statistically specified evaluation criteria namely Cohen's Kappa, ROC, TSS, AUC and Accuracy. The average score was calculated. Accordingly, Random Forest (RF) and Gradient Boosting Machine (GBM) are found to be the best-fitted models. This finding is in conformity with the reports of Liu (2014) and Almayyan (2016).

Table 4.17: Model evaluation of five different machine learning models

Models	Kappa	ROC	TSS	AUC	Accuracy
RF	0.571	0.985	0.868	0.985	0.924
GBM	0.426	0.865	0.576	0.865	0.752
MARS	0.202	0.723	0.362	0.723	0.698
SVM	0.248	0.724	0.229	0.724	0.451
NB	-0.2	0.707	-0.099	0.706	0.279

4.4.7 Average risk prediction

Data was analysed to find out average risk prediction of Bluetongue disease outbreak among Sheep and Goats for each district of Karnataka and results are presented in Table 4.18. The risk score ranges from 0 to 0.60 and risk was classified into different groups such as very high risk (>0.50), high risk (0.41-0.50), medium risk (0.31-0.40), low risk (0.21-0.30) and very low risk or no risk (0.00-0.20). Data from Fig. 4.16 indicated that the district *viz.,* Bengaluru Rural and Mysuru indicating very high risk (>0.50), Yadgir, Mandya, Vijayapura, Ramanagara, Tumakuru, Bidar, Chikkaballapura, Chamarajanagar, Kolar, Raichur and Hassan indicating high risk (0.41 to 0.50), Kalaburagi, Bagalakote and Bengaluru Urban indicating medium risk (0.31 to 0.40), Belagavi, Chikkamagaluru, Ballari, Gadag, Haveri and Kodagu indicating low risk (0.21 to 0.30) and rest of the districts were in very low risk or no risk. From the findings, it is observed the best prediction was obtained by using combined prediction results of different models and averaging the score, instead of relying on a single best model.

Table 4.18: Average risk prediction of Bluetongue disease outbreak among Sheep and Goats

Sl. No.	District	Average risk score	Risk range	Risk level
1	Bengaluru Rural	0.53	>0.50	Very high
2	Mysuru	0.51		
3	Yadgir	0.5	0.41 to 0.50	High
4	Mandya	0.49		
5	Vijayapura	0.47		
6	Ramanagara	0.46		
7	Tumakuru	0.46		
8	Bidar	0.45		
9	Chikkaballapura	0.45		
10	Chamarajanagar	0.44		
11	Kolar	0.44		
12	Raichur	0.44		
13	Hassan	0.43		
14	Kalaburagi	0.39	0.31 to 0.40	Medium
15	Bagalakote	0.38		
16	Bengaluru Urban	0.33		
17	Belagavi	0.3	0.21 to 0.30	Low
18	Chikkamagaluru	0.28		
19	Ballari	0.22		
20	Gadag	0.22		
21	Haveri	0.22		
22	Kodagu	0.21		
23	Shivamogga	0.2	0.00 to 0.20	Very low
24	Chitradurga	0.19		
25	Koppal	0.19		
26	Dharwad	0.18		
27	Davanagere	0.17		
28	Dakshina Kannada	0.15		
29	Uttara Kannada	0.08		
30	Udupi	0.06		

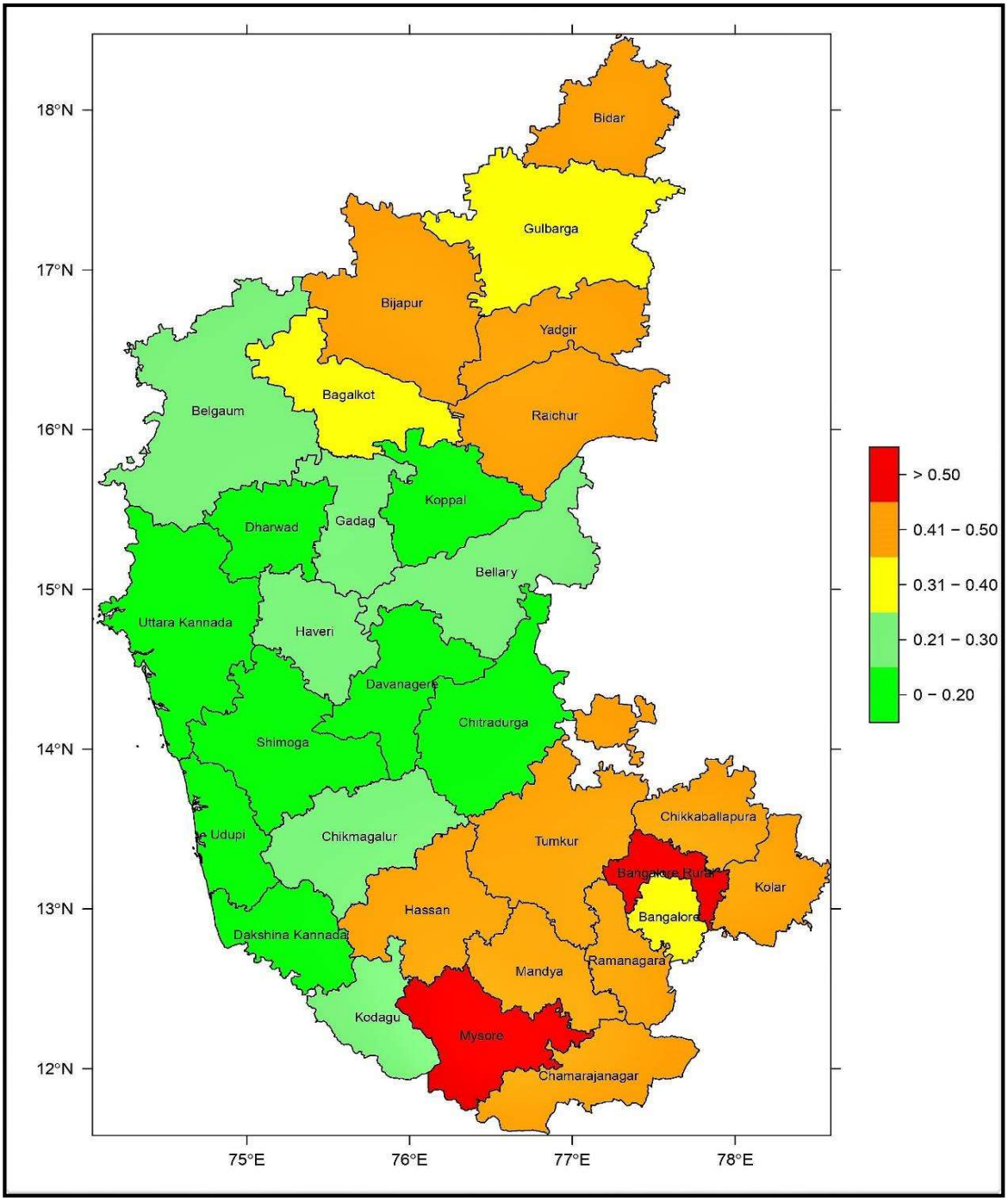

Fig. 4.16: Average risk prediction of Bluetongue disease outbreak among Sheep and Goats

4.4.8 Estimation of Basic reproduction number (R_0)

The final step of risk assessment is to estimate the basic reproduction number (R_0) and to model R_0 with risk already estimated using various risk factors. The outcome obtained from this step is more projectable and interpretable for developing appropriate preventive measures. R_0 was explained as the actual number of secondary cases to be predicted that the one primary case can generate in a susceptible population. The daily incidence and the magnitude of outbreak are heavily reliant on the value of R_0, suggesting more of the livestock population would be infected in the future. This data can help with disease management in the region.

According to years in the study from 2005-2019, R_0 was calculated for the districts falling in the significantly clustered region generated by SaTScan and Getis Ord index and the results of estimation of basic reproduction number (R_0) of Bluetongue disease outbreak among Sheep and Goats are presented in Table 4.19 and Fig. 4.17. The R_0 values above 1.00 indicate the districts with an increased trend of disease occurrence, severity, high risk and vice-versa. Further, the regions having low R_0 possibly might shift to high R_0 values in near future due to the migration of infected animals from one place to another. This result was in conformity with the findings of Li *et al.* (2020).

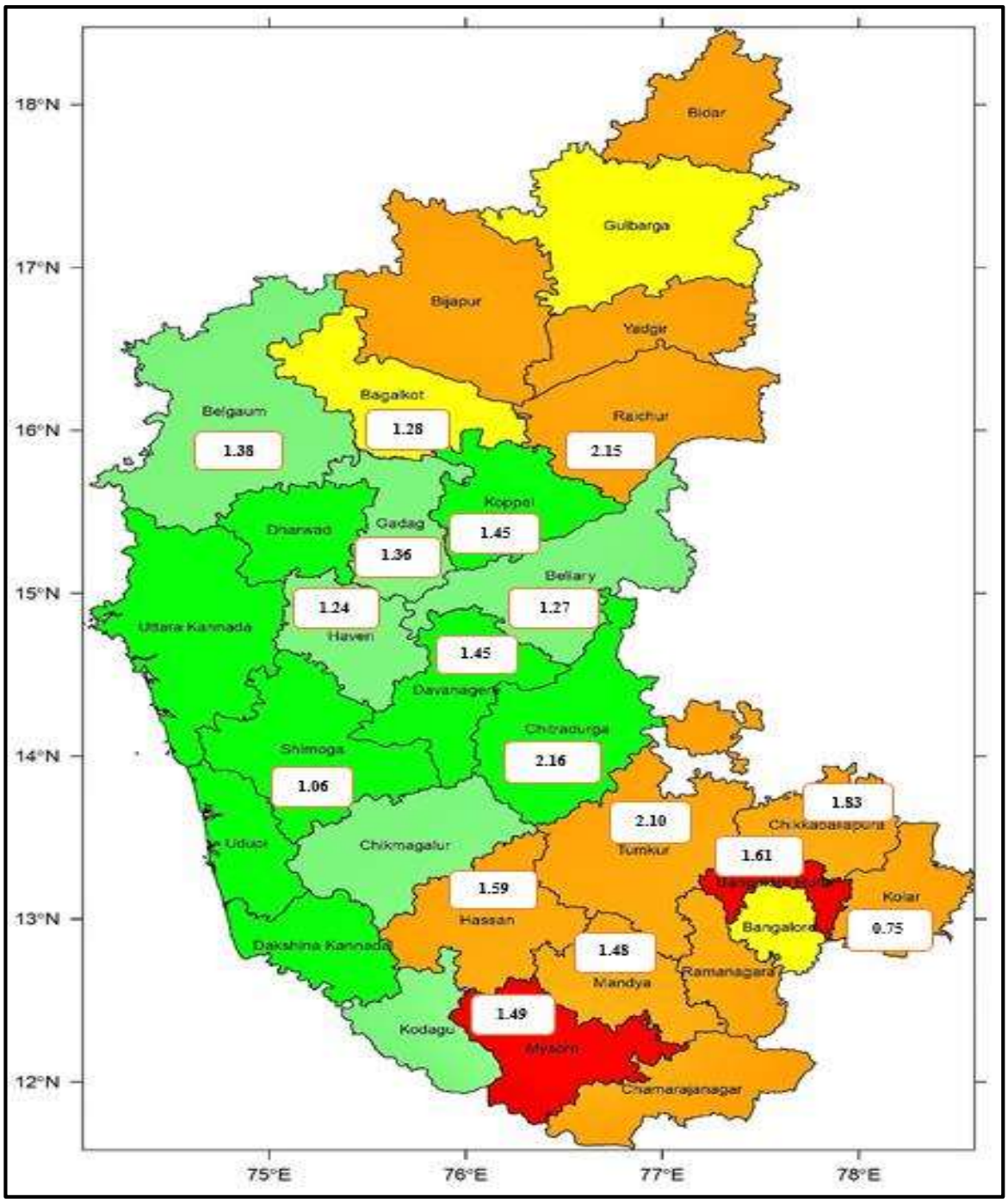

Fig. 4.17: Estimation of Basic reproduction number (R_0) of Bluetongue disease outbreak among Sheep and Goats

Table 4.19: Estimation of Basic reproduction number (R_0) of Bluetongue disease outbreak among Sheep and Goats

Sl. No.	District	R_0 Value
1	Chitradurga	2.16
2	Raichur	2.15
3	Tumakuru	2.10
4	Chikkaballapura	1.83
5	Bengaluru Rural	1.61
6	Hassan	1.59
7	Mysuru	1.49
8	Mandya	1.48
9	Davanagere	1.45
10	Koppal	1.45
11	Belagavi	1.38
12	Gadag	1.36
13	Bagalakote	1.28
14	Ballari	1.27
15	Haveri	1.24
16	Shivamogga	1.06
17	Kolar	0.75