Spatial distribution of dengue fever incidence in Kerala state – A retrospective study

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Received: March 19, 2019; **Accepted:** April 15, 2019

ABSTRACT

Background: Dengue fever is a rapidly spreading viral infection. The incidence of dengue fever cases in Kerala is still rising from the year 2006 onward in spite of several measures. The pattern of dengue fever distribution is not uniform in all the districts. Only some districts are reporting a high number of cases in every year. Based on this background, the present study conducted to observe and analyze the spatial distribution pattern of dengue fever incidence in Kerala state. **Objectives:** The objectives of the present study are to assess the spatial autocorrelation of dengue fever incidence in Kerala state and to identify the significant spatial clusters having a high or low incidence of dengue fever in Kerala state. **Materials and Methods:** The present study is a retrospective observational study using the secondary data of Kerala state. Year wise incidence of dengue fever cases in each district was measured. Since 2011, hierarchical maps of the incidence of dengue fever in different districts were created using QGIS software. Spatial autocorrelation of dengue fever incidence in every year was tested using GeoDa software. Global Moran's i value was measured in each year, local indicators of spatial association maps prepared to observe the spatial distribution of dengue fever incidence in Kerala. **Results:** Incidence of dengue fever cases is in increasing trend in every district, but in the year 2014 and 2018, the incidence was decreased compared to the previous year. Among all the years, 2013, 2016, and 2017 showed significant positive global spatial autocorrelation. Kollam district is showed a high-high spatial pattern. Low-low cluster areas were observed in North Kerala from 2011 to 2013 and in central Kerala in the years 2016 and 2018. **Conclusion:** Spatial distribution of dengue fever incidence is not uniform every year. Kollam district significantly reporting the high incidence and surrounded by high incidence districts. Kannur, Malappuram, Palakkad, Wayanad, Thrissur, and Ernakulam districts significantly reporting the low incidence of dengue fever and they were surrounded by low incidence districts. This type of analysis helps identify areas where control efforts can be intensified strategically thus optimizing resources Larger studies can be conducted at subnation or nation level, to eliminate the border issues between states and for better identification of local spatial clusters of dengue fever incidence.

KEY WORDS: Dengue fever; Global Moran's I; Hierarchical Maps; Local Indicators of Spatial Association Maps; Spatial Analysis

Access this article online	
Website: http://www.ijmsph.com	Quick Response code
DOI: 10.5455/ijmsph.2019.0408515042019	

INTRODUCTION

Dengue fever is a rapidly spreading viral infection characterized by sudden onset of fever, rashes, muscle aches, joint pain, and leukopenia. A dengue patient usually recovers within 14 days. Dengue fever is caused by any one of the four serotypes of dengue virus which are spread by the bite of female *Aedes* mosquitoes.[1] The actual numbers of dengue cases are underreported and many cases are misclassified. The disease became endemic in several tropical and subtropical countries throughout the world.[2] Globally, around 3.9 billion people are at risk of dengue fever in 128 countries.[3] The global incidence of dengue has grown dramatically in recent decades. Several studies stated the reasons of increasing trends of dengue fever cases as population growth, urbanization, formation of slums, and increased population density.[4-6] The rise in population density and rise of vector burden due to favorable environmental conditions such as rainfall, humidity, and temperatures result in the increasing trend of dengue fever cases.[7]

India is the second most populous country in the world. According to census 2011, population density of India is 382/sqkm.[8] In the year 2006, India saw the worst outbreak of dengue fever in New Delhi. Kerala state also reported high number of dengue fever cases in the year 2006 and stood next to New Delhi.[9] The incidence of dengue fever cases in Kerala is still rising from the year 2006 onward in spite of several measures. The pattern of dengue fever distribution is not uniform in all the districts. Only some districts are reporting a high number of cases in every year.

Spatial analysis of the distribution pattern of vector borne diseases is very much useful to identify the areas, which are significantly reporting a high number of cases or low number of cases every year. Environmental conditions such as rainfall, humidity, water stagnant areas, and mosquito burden are risk factors associated with the incidence of vector borne diseases. These environmental conditions may vary from place to place and causing unequal distribution pattern of vector born diseases.

Incidence of dengue fever is also not uniform in all the districts might be due to different environmental conditions in different districts. Spatial autocorrelation test will reveal the correlation of dengue fever incidence with space. Spatial analysis of local clustering is also useful to detect the areas which are significantly reporting high incidence every year. Identifying such districts would be beneficial in optimally using resources especially during epidemic periods. Instead of deploying resources to uniformly across the state, high-risk areas could be targeted. However, a very limited number of studies were conducted to assess the spatial autocorrelation of dengue fever cases and identify the significant spatial clusters of dengue fever cases.

The surveillance system in Kerala state is collecting information about the incidence of dengue fever cases daily and giving the consolidated annual reports since 2011. The presence of data without converting into valuable indicators such as incidence of dengue fever cases is not useful to take better decisions by health-care administrators to control the burden of dengue fever in Kerala state. The data of a number of dengue fever cases were not used for spatial analysis to detect the significant high incidence districts and low incidence districts in Kerala state.

Based on this background, the present study was conducted mainly with two objectives, namely to assess the spatial autocorrelation of dengue fever incidence in Kerala state and to identify the significant spatial clusters having a high or low incidence of dengue fever in Kerala state.

MATERIALS AND METHODS

The present study is a retrospective observational study using the secondary data of Kerala state. Institutional Ethics Committee approval was obtained to conduct the study. Director of Public Health of Kerala state is providing annual reports of district wise communicable disease incidence since 2011 on its website.[10] These annual reports were downloaded for a period of 7 years, i.e., from 2011 to 2018 and data of dengue fever cases were extracted from the downloaded pdf files. Data of population residing in various districts of Kerala state were collected from census 2011.[11] Kerala state shapefile with district wise administrative division was downloaded from http://www.gadm.org website.[12]

Procedures and Spatial Analysis

Year wise incidence of dengue fever cases in each district was measured, and hierarchical mapping of incidence of dengue fever in different districts was done since 2011 using QGIS software. Based on the incidence of dengue fever cases, all the districts were categorized into four groups using the natural breakup method. It is a commonly adopted scaling method maximizing the variance between scales while minimizing it within the scales.[13]

Spatial autocorrelation of dengue fever incidence in every year was tested using GeoDa software. The spatial autocorrelation was tested using two forms of Univariate Moran's I, namely Global and local.[14,15] Global Moran's I is used to assess the overall spatial distribution characteristics in an area as a whole. Local Moran's I, an indicator for a particular area, is used to detect the spatial clusters.[16] Global and local Moran's I values were calculated in each year based on the incidence of dengue fever in Kerala state. Distribution patterns of dengue fever incidence in Kerala state were compared using the scatter plot graphs and incidence maps.

Spatial Weight Matrix

A spatial-weighted matrix [W] was created which serves as the premise for spatial autocorrelation analysis. It is an $n \times n$ matrix containing the location information between each pair of target geographic units.[17,18] Wij is 1 means, geographic units, such as districts, I and j are adjacent, and $Wij = 0$ means *i* and *j* do not border each other. In our analysis, a geographic unit is a district of Kerala state. Influence of the number of neighbors was eliminated by row-standardization of the matrix.

Global Moran's I Statistic

Among the different indicators used to assess geographic distribution of target observations, Moran's I is universally adopted.[19] It directly indicates the clustering of similar incidence in different districts of Kerala state. It will act as a powerful tool to explore the spatial autocorrelations between districts. The global Moran I ranges between −1 and + 1. It shows the overall relationship of all the districts in the whole of Kerala state. Global Moran's I = 1 means a positive spatial autocorrelation whereas Global Moran's I = −1 means no spatial autocorrelation. Spatial correlation is more significant when the value approaches −1 and 1, whereas Global Moran's I = 0 means a random geographic distribution of all the districts.[20]

Moran Scatterplots

Moran scatterplots were used to depict the spatial distribution patterns of the districts. It will reveal a relationship between the incidence of each district and the weighted mean value of the bordering districts. The horizontal axis is for the incidence of dengue fever in each district, whereas the vertical axis stands for the weighted mean value of bordering units of each plot.[21] Each of the 14 districts is represented by one plot in the diagrams. The slope of the fitting line is represented by global Moran's I.

Moran scatterplots prepared for each year from 2011 to 2018, each plot has four quadrants split by the horizontal and vertical axes represent different spatial autocorrelation relationships. Quadrants I has high ± high and quadrant III had low ± low, pattern. It indicates a positive spatial autocorrelation. Quadrant II has high ± low and quadrant IV has low ± high pattern. They will reveal a negative spatial autocorrelation. Mean incidences of all the districts were calculated every year. Districts were categorized into two groups, namely districts above the mean and districts below the mean. If the district above the mean surrounded by districts with values above average it is considered as high ± high, i.e., quadrant I. If the districts above-average incidence surrounded by districts with sub-average value, they were marked quadrant II.[22] Districts in quadrants III and IV were also marked using a similar principle. Like this, all districts are categorized into four groups in line with the spatial autocorrelation relationships in every year.

Local Moran's I Statistic

Local Indicator of Spatial Association (LISA), also known as Local Moran's I, is a measure to describe the local spatial distribution characteristics.[22] Local Moran's I range between −1 and +1. Local Moran's I = 1 means clustering of similar values, whereas local Moran's I = −1 means, clustering of dissimilar values, i.e., no clustering of cases. Proximity to −1 and 1 means a significant trend of clustering of similar or dissimilar values whereas local Moran's I approaching 0 indicates the nonsignificant trend of clustering of cases.[23] Local Moran's I is used to make the year wise univariate LISA cluster maps from 2011 to 2018.

Univariate LISA Cluster Map

Univariate LISA cluster maps were created to depict the spatial cluster areas. It is also connected with Moran scatterplots. The districts lie far from the origin of the coordinate in the scatterplots is deemed as outliers. It indicates that they are significant values among districts in the same quadrant and were highlighted in LISA maps.[22] Four different types of spatial clusters were highlighted using different colors in LISA maps in accordance with the four quadrants of the diagram of the scatterplots. Significance of local Moran's I was tested with Monte Carlo randomization (99,999 permutations).[18] Districts whose local Moran's I reach a significance level of 0.05 or above were displayed on Kerala's district map. The districts whose $P > 0.05$, were classified as not significant districts on the maps.

Software Tool

Microsoft-Excel software, QGIS software and GeoDa software were used for the analysis. The global and local Moran's I and Moran scatterplots are computed using GeoDa 1.12.1.[24]

RESULTS

Dengue Fever Incidence

Table 1 describes the dengue fever incidence per 1 lakh population in different districts from the year 2011 to 2018. Incidence of dengue fever cases is in increasing trend in every district, but in the year 2014 and 2018, the incidence was decreased compared to the previous year. Table 2 depicts the proportion of dengue fever cases in different districts in Kerala state in each year from 2011 to 2018. Thiruvananthapuram is the district with a high incidence of dengue fever and also contributing major proportion of all the cases in Kerala state from the year 2011 to 2017. Pathanamthitta is the district with high incidence and contributed major proportion of dengue fever cases in total Kerala state in the year 2018. Districts with the lowest incidence of dengue fever and districts contributing a lowest proportion of dengue fever cases were varying from year to year.

Figure 1 shows the dengue fever incidence per 1 lakh population in different districts from the year 2011 to 2018.

Table 1: Incidence (Per 100,0000) of Dengue fever cases in different districts in Kerala state from 2011 to 2018

Year/ District	Alappuzha	Ernakulam	Idukki	Kannur	Kasaragod	Kollam	Kottayam	Kozhikode	Malappuram	Palakkad	Pattanamtitta	Thiruvananthapuram	Thrissur	Wayanad
2011	1.69	4.24	1.17	0.63	0.92	1.29	3.14	1.23	0.51	0.61	1.25	26.20	0.90	0.98
2012	3.81	7.46	7.76	4.52	5.01	11.47	5.06	1.74	3.96	3.84	11.94	78.40	5.24	5.14
2013	8.65	10.66	33.27	6.11	8.91	37.40	13.35	6.62	12.72	5.41	40.42	134.31	6.94	6.12
2014	2.16	4.54	1.80	2.09	2.28	5.58	0.97	10.94	3.55	1.42	15.95	41.01	4.63	5.38
2015	7.38	7.40	11.45	5.92	24.11	18.74	3.18	23.27	6.69	5.16	17.04	31.75	7.66	19.21
2016	39.43	13.13	11.27	3.72	12.21	81.38	17.59	5.75	6.03	4.84	51.03	69.14	10.78	27.28
2017	64.62	15.05	15.15	24.93	28.68	108.41	21.73	43.87	23.41	81.39	58.88	271.25	30.09	56.64
2018	7.00	5.39	4.78	13.40	49.18	9.41	6.28	8.00	21.32	10.50	30.98	9.48	6.44	5.75

Table 2: Annual Proportion of Dengue fever cases in different districts in Kerala state from 2011 to 2018

District	Alappuzha	Ernakulam	Idukki	Kannur	Kasaragod	Kollam	Kottayam	Kozhikode	Malappuram	Palakkad	Pattanamtitta	Thiruvananthapuram	Thrissur	Wayanad
2011	2.76%	10.66%	1.00%	1.23%	0.92%	2.61%	4.75%	2.91%	1.61%	1.30%	1.15%	66.33%	2.15%	0.61%
2012	2.00%	6.04%	2.12%	2.93%	2.44%	3.70%	3.85%	1.08%	4.02%	2.66%	3.53%	60.33%	4.27%	1.04%
2013	2.32%	4.41%	4.65%	2.03%	2.22%	6.16%	5.19%	2.10%	6.59%	1.91%	6.10%	52.81%	2.88%	0.63%
2014	1.81%	5.85%	0.78%	2.16%	1.77%	2.86%	1.18%	10.83%	5.73%	1.57%	7.50%	50.24%	6.00%	1.73%
2015	3.82%	5.91%	3.09%	3.79%	11.57%	5.96%	2.38%	14.27%	6.68%	3.52%	4.96%	24.09%	6.15%	3.82%
2016	11.62%	5.97%	1.73%	1.36%	3.34%	14.74%	7.52%	2.01%	3.44%	1.88%	8.46%	29.90%	4.93%	3.09%
2017	6.25%	2.25%	0.76%	2.86%	1.71%	12.99%	1.95%	6.16%	4.38%	10.40%	3.21%	40.72%	4.27%	2.11%
2018	3.65%	4.34%	1.30%	8.28%	15.75%	6.07%	3.04%	6.05%	21.48%	7.23%	9.09%	7.67%	4.92%	1.15%

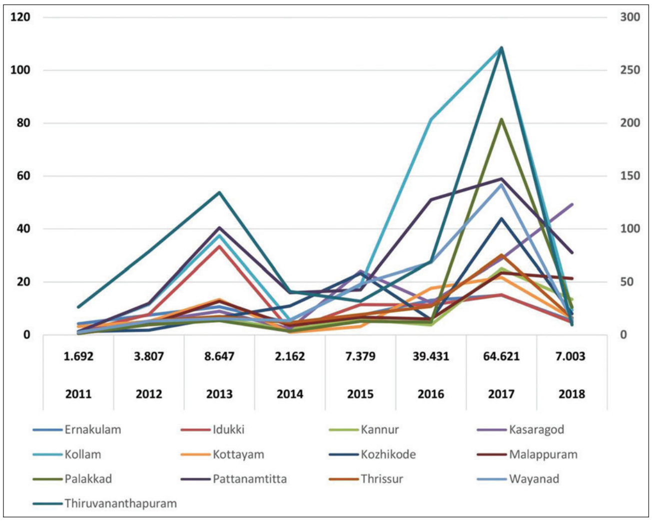

Figure 1: Incidence of dengue fever per 1 lakh population in different districts of Kerala from the year 2011 to 2018

Thiruvananthapuram district which was having a very high incidence compared to the others is plotted on the secondary axis for ease of visualization. The incidence of dengue fever cases is in increasing trend in every district. In 2013 and 2017, all the districts have shown higher incidence matching a cyclical trend. In two districts, namely Kollam and Pathanamthitta, the epidemic trend started in 2016 itself. Kasaragod and Kozhikode districts have a different cyclical pattern from the other districts with the peaks occurring in 2015. Kozhikode showed higher numbers in 2017 and Kasaragod in 2018. These could be due to different virus strains circulating

Global Spatial Autocorrelation

Table 3 shows the Global Moran's I value of dengue fever incidence from the year 2011 to 2018. Among all the years, 2013, 2016, and 2017 showing significant positive global spatial autocorrelation. In the reaming years, global Moran's I value is nearer to zero. In these 3 years, although most of the districts present in the III quadrant, some districts present in the first quadrant also.

Figure 2 illustrates the Moran scatterplots of the dengue fever incidence from the year 2011 to 2018. Moran's I values are represented by the slope of the fitting lines. A greater slope means a greater value of Moran's I, suggesting a more uneven distribution of the incidence of the dengue fever in the Kerala state. Each plot in the diagrams stands for a district. As explained in the method, the horizontal and vertical axes split each diagram into four quadrants. The plots in quadrants I and III represent the high ± high and low ± low distribution patterns of the districts, whereas quadrants II and IV stand for a high ± low and low ± high distribution pattern.

Some districts present in the first quadrant in the year 2013, 2015, 2016, and 2017. In the remaining years, no district was present in the first quadrant. In the year 2014, 2015, and 2017, some districts present in the second quadrant. In the year 2018, most of the districts present in the III quadrant. In the year 2018, some districts present in the IV quadrant The diagrams of scatterplots only reveal the extent to which the dengue fever incidence unevenly distributed in the different districts of Kerala state in general. More details about the local spatial distribution characteristics are needed.

Table 3: Global Moran's I value of Dengue fever incidence from 2011 to 2018

Year	Global Moran's I value
2011	-0.025
2012	0.084
2013	0.244
2014	-0.022
2015	0.097
2016	0.739
2017	0.339
2018	0.030

Local Spatial Autocorrelation

Figure 3 depicts a hierarchical map of the incidence of dengue fever per 1 lakh population in the 14 districts of Kerala state from the year 2011 to 2018. Four scales, indicated by worse (dark blue) to better (white), are created with the natural break method. It is a commonly adopted scaling method to maximize the variance between scales while minimizing it within the scales. It can be observed that in central Kerala, districts showing fewer incidences when compared to North and South Kerala. From 2011 to 2017, high incidence of dengue fever was observed in South Kerala, but 2018 high incidence was observed in North Kerala. The series of maps from the year 2011 to 2018 revealed that districts adjacent to high incidence districts reporting high incidence in the next coming year.

The spatial cluster areas of dengue fever incidence were detected by local Moran's I are visualized in the univariate LISA maps in Figure 4. As the incidence of dengue fever displayed positive autocorrelation in the years 2013, 2016, and 2017, there were high-high (HH) and low-low (LL) cluster areas on the maps. It is easy to conclude that every year, dengue fever reveals a unique spatial distribution pattern. It was observed that Kollam district is showing HH spatial pattern. LL cluster areas were observed in North Kerala from 2011 to 2013 and in central Kerala in the years 2016 and 2018.

DISCUSSION

The study of spatial distribution pattern is very useful to reduce the burden of dengue fever incidence. In the current

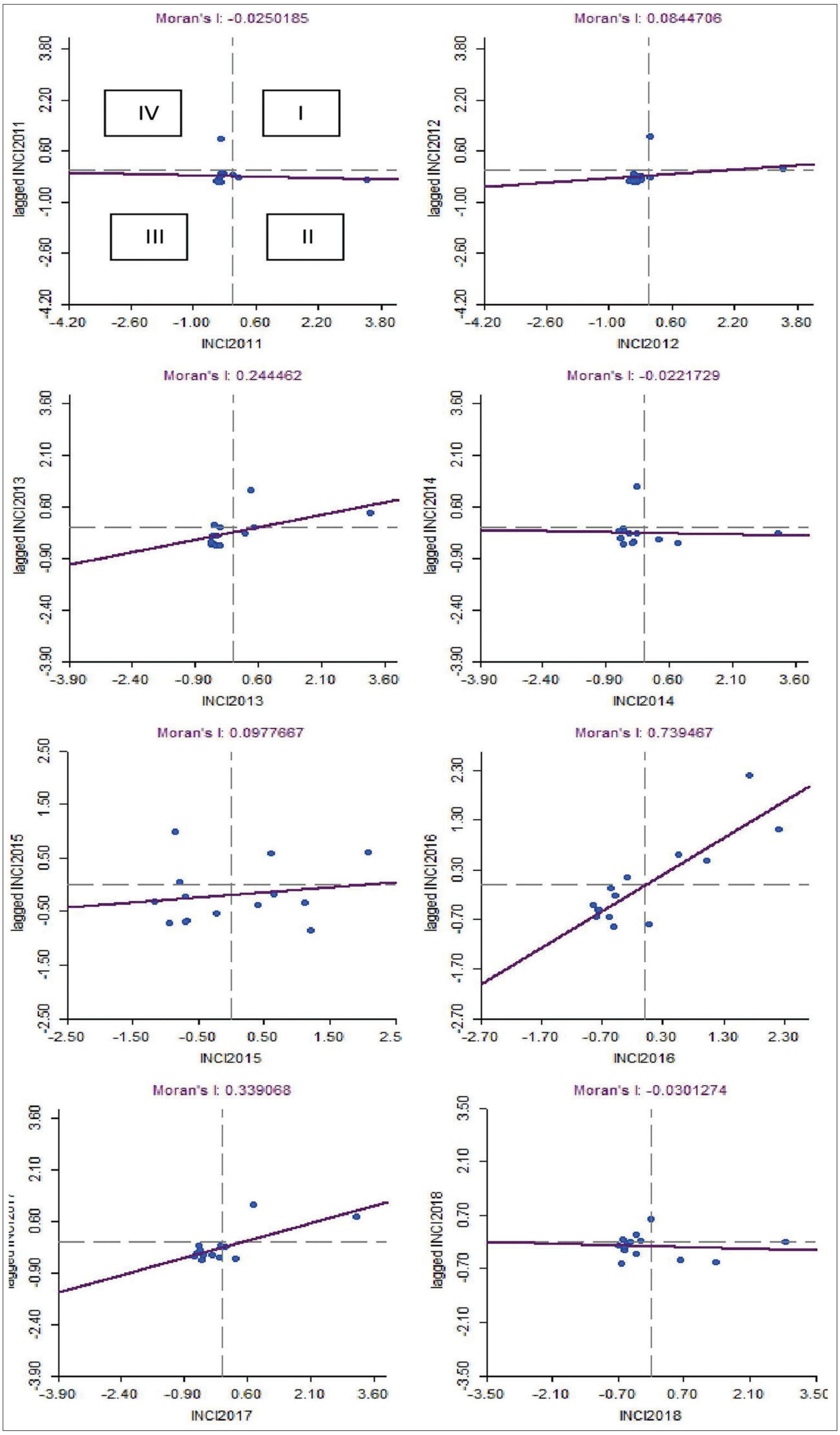

Figure 2: Moran's scatter plots of dengue fever incidence n Kerala state from 2011 to 2018

study, the incidence of dengue fever cases in Kerala state was analyzed and their spatial distribution patterns were observed for a period of 7 years. The descriptive statistics of dengue fever cases revealed that there is a wide variation of incidence among the various districts of Kerala state. It indicated that the distribution of dengue fever cases is not in a uniform pattern. Global Moran's I value shows positive value in 3 years, namely 2013, 2016, and 2017 and in the remaining years, it is

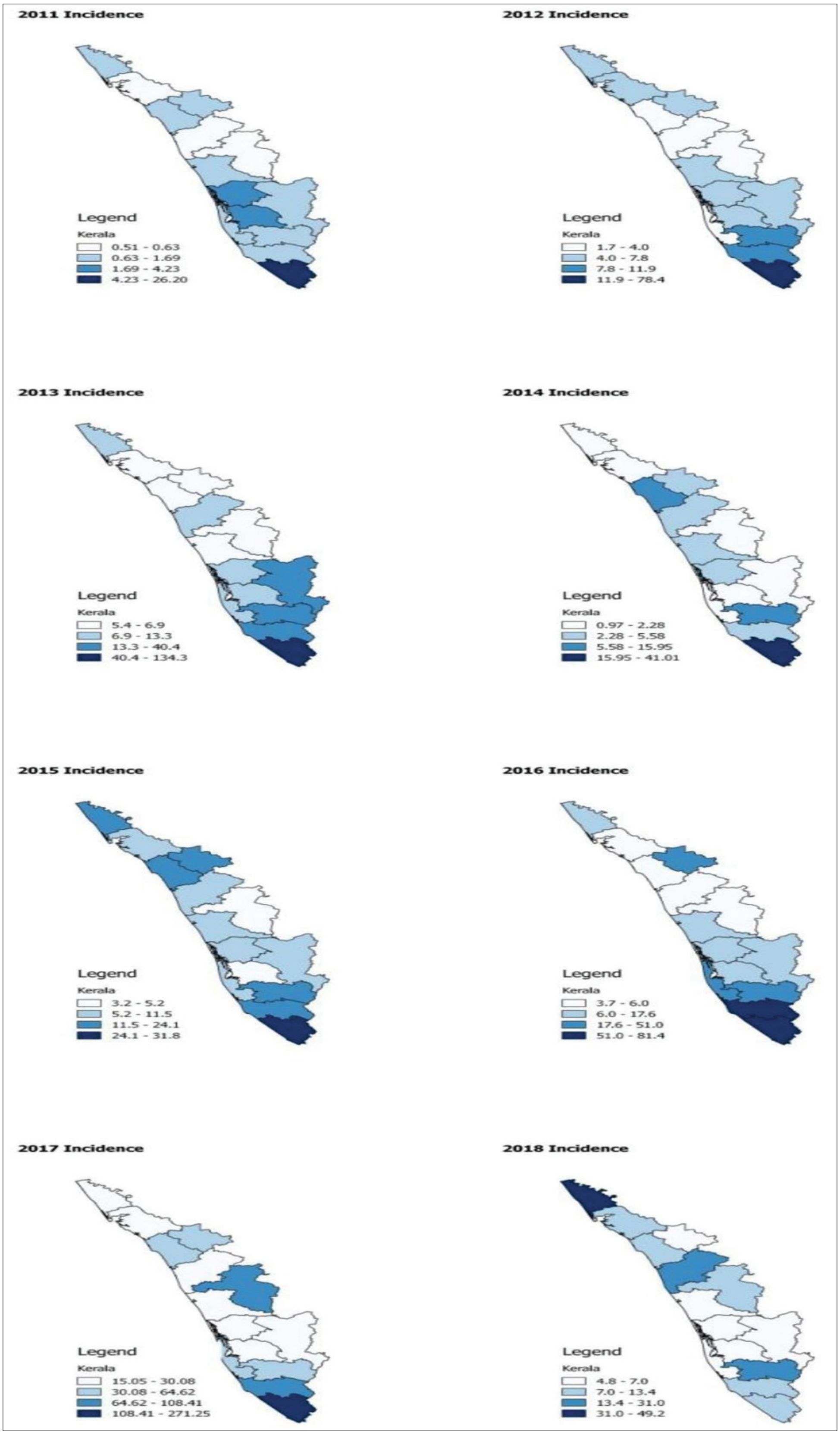

Figure 3: Hierarchical mapping of dengue fever incidence in Kerala state from 2011 to 2018

nearer to zero. Scatter plots revealed that some districts were present in the first quadrant, showing HH distribution pattern in the 4 years only, i.e., 2013, 2015, 2016, and 2017. LISA maps showed that Kollam is the only district significantly reporting HH spatial distribution pattern and highlighted in dark red color. Kozhikode, Malappuram, Palakkad, and

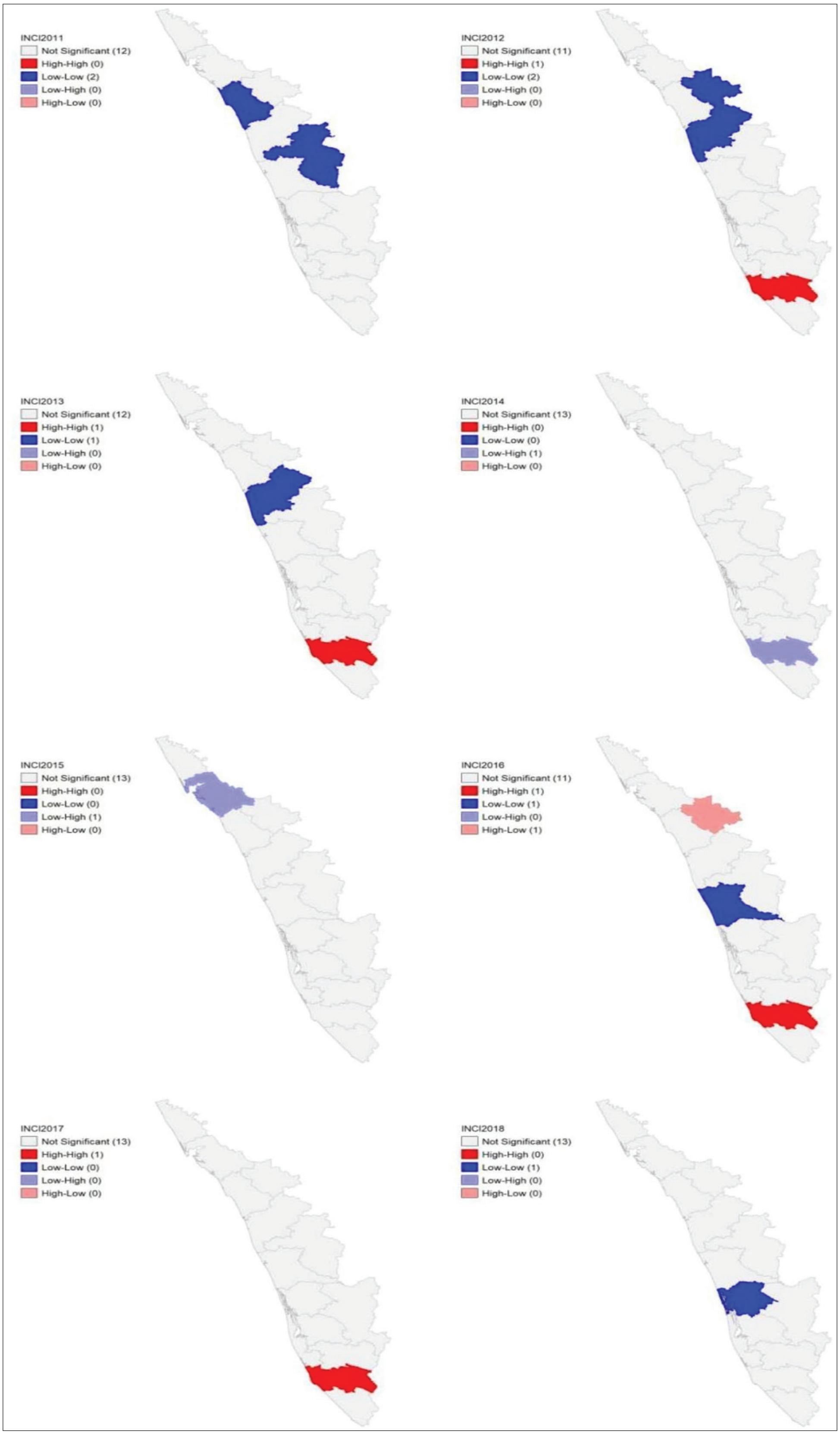

Figure 4: Local indicator of spatial association maps of dengue fever incidence in Kerala state from 2011 to 2018

Wayanad significantly depicted LL distribution pattern in the years 2011, 2012, and 2013 and were highlighted in dark blue color. Thrissur and Ernakulam significantly depicted LL distribution pattern in the years 2016 and 2018, respectively, and were highlighted in the dark blue color. Remaining districts are not showing any significant pattern in any year. It indicated that the spatial distribution pattern is not uniform every year.

The wide variation of incidence of dengue fever cases among the various districts of Kerala state indicated that the distribution of dengue fever cases is not in a uniform pattern and depends on the local factors such as population density, rainfall, and altitude. Many studies revealed the association of various environmental and geographic conditions with the incidence of dengue fever.[4,25-27] Although the incidence varies in different districts, there is a possibility of clustering of districts with similar incidence. The presence of clustering of districts can be assessed by testing spatial autocorrelation of dengue fever incidence using Global Moran's I test.[14,15]

Global Moran's I value shows positive value in 3 years, namely 2013, 2016, and 2017. During the period 2011 and 2012, the incidence is very low, in the remaining years 2014, 2015, and 2018 the incidence was reduced. It was observed that, when incidence was low, global Moran's I value is nearer to zero. It indicated the random distribution of dengue fever incidence. It might be due to less chance of clustering of districts when the incidence was low.

LISA maps are used to identify the spatial clusters of infectious diseases in many studies.[16,22,28] In the current study, LISA maps depicted the districts having a significant local autocorrelation. Districts having significant spatial distribution pattern were highlighted in the map. Districts which had significant high-high spatial distribution pattern were highlighted in dark red color. Kollam is the only district significantly reporting HH spatial distribution pattern and highlighted in dark red color. Although Thiruvananthapuram reported high incidence every year, it had only one adjacent district and Kollam had three high incidence districts in its surrounding, thus highlighted in dark red color. Wayanad significantly reported high-low distribution pattern in the year 2016 and highlighted in pale red color. Kollam and Kannur districts significantly showed low-high distribution pattern in the years 2014 and 2015, respectively, and were highlighted in pale blue color. Kozhikode, Malappuram, Palakkad, and Wayanad significantly depicted LL distribution pattern in the years 2011, 2012, and 2013 and were highlighted in dark blue color. Thrissur and Ernakulam significantly depicted LL distribution pattern in the years 2016 and 2018, respectively, and were highlighted in the dark blue color. Remaining districts are not showing any significant pattern in any year. It indicated that the spatial distribution pattern is not uniform every year.

Reasons for non-uniform spatial distribution pattern of dengue fever incidence might be, variation in the rainfall, availability of health-care services, migration of population, number of construction sites, etc. Most of the districts in Kerala state had borders with other districts in Tamil Nadu and Karnataka. Thus, the influence of neighbor districts in other states may cause unevenness in the distribution of dengue fever incidence in Kerala state.

Strengths and Limitations

The current study was conducted with a data of 7 years period instead of 1 year data. It improved the reliability of the results of spatial analysis. It also enabled to observe the movement of significant spatial clusters over a period of time.

The current study used the annual reports of dengue fever incidence. If monthly reports are available, it would be easier to understand the clustering of districts in different months or different seasons and to understand the movement of dengue fever incidence in a year across districts. The study is based on routine surveillance data of the state. The cases may not be confirmed dengue.

CONCLUSIONS

Dengue fever incidence spatial distribution pattern is not uniform every year. Kollam district significantly reporting the high incidence and surrounded by high incidence districts. Kannur, Malappuram, Palakkad, Wayanad, Thrissur, and Ernakulam districts significantly reporting the low incidence of dengue fever and were surrounded by low incidence districts. Data standardization across states would help analysis at subnation or nation level, eliminating the border issues between states. This would help better identification of local spatial clusters of dengue fever incidence. Identification of clusters would help health-care administrators optimize resources during an impending epidemic, take control measures thereby reducing the burden of cases.

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How to cite this article: Nayak MSDP, Narayan KA. Spatial distribution of dengue fever incidence in Kerala state – A retrospective study. Int J Med Sci Public Health 2019;8(6):430-439.

Source of Support: Nil,**Conflict of Interest:** None declared.