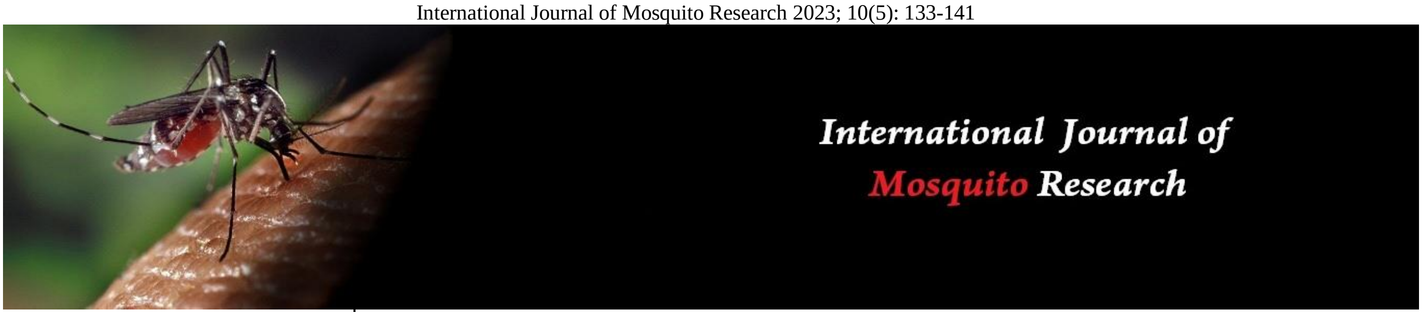

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25 + Years of Dengue in Kerala, India: A comprehensive time series analysis and future projections

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Abstract
Dengue fever is a mosquito-borne viral infection among the 20 prioritized Neglected Tropical Diseases recognised by the World Health Organization (WHO). Its incidence has increased globally and in India in the past two decades. Kerala, India, reported its first case of dengue fever in 1997, and the incidence has gradually increased since then, making dengue fever an endemic and serious health problem. This study is a descriptive study of the incidence and mortality of dengue fever in Kerala from its first report till the present. The study will use exploratory data analysis, time series analysis, and predictive analysis to understand the scale of dengue fever spread over time and near future.

Keywords: Dengue, Kerala, R Studio, time series analysis, forecast

1. Introduction
Dengue is a vector-borne viral infection caused by a Flavivirus, the dengue virus (DENV), transmitted by *Aedes aegypti* and *Ae. Albopictus* species of mosquitoes. Although many infections with DENV result in no symptoms or mild illness, there are instances where DENV can lead to more severe conditions, such as dengue haemorrhagic fever, and in some cases, even death.
Neglected tropical diseases (NTDs) are enduring ailments of poverty that impose a significant human, social, and economic burden on over 1 billion people worldwide, primarily in tropical and subtropical regions among vulnerable and marginalized populations. Dengue is among the 20 prioritized NTDs recognised by the World Health Organization (WHO) [1].
The global incidence of dengue has significantly risen in recent decades, with reported cases to the WHO surging from 505,430 in 2000 to 5.2 million in 2019 and has become endemic in more than 100 countries [2]. The first recorded instance of Dengue fever in India was reported in 1956, originating in the Vellore district of Tamil Nadu. The first dengue haemorrhagic fever outbreak occurred in Calcutta, West Bengal, in 1963 [3]. The number of states and the Union Territories (UTs) reporting cases increased from 8 (7 states and one UT) in 2000 to 35 (28 states and 7 UTs) in 2021 [4]. In 2022, India reported an overall of 233251 incidences and 303 mortalities [5].
Kerala, located in south-western India, comprises 14 administrative districts (Figure 1). Based upon geographical, historical, and cultural similarities, the 14 districts of Kerala are generally grouped into three regions: Northern, Central and Southern Kerala. The first incidence of Dengue fever in Kerala was reported from Kottayam in 1997 [6].
This study is a descriptive study of the incidence and mortality of dengue in Kerala from its first report till the present. The study will include exploratory data analysis, Time series analysis and Predictive analysis

2. Methodology
2.1 Epidemiological data: Annual data on communicable diseases from 2011-2021 was retrieved from The Directorate of Health Services, Kerala website [7].

Annual data on communicable diseases from 2006 -2010 were extracted from the report published by the State Surveillance Unit of Integrated Disease Surveillance Project on the same website [8]. Annual data on the incidence and mortality of dengue from 2001-2005 was extracted from The National Vector Borne Disease Control Programme (NVBDCP) website [9]. Annual data on dengue cases and deaths from 1997 -2000 was extracted from Tyagi BK *et al.*, 2006 [10].

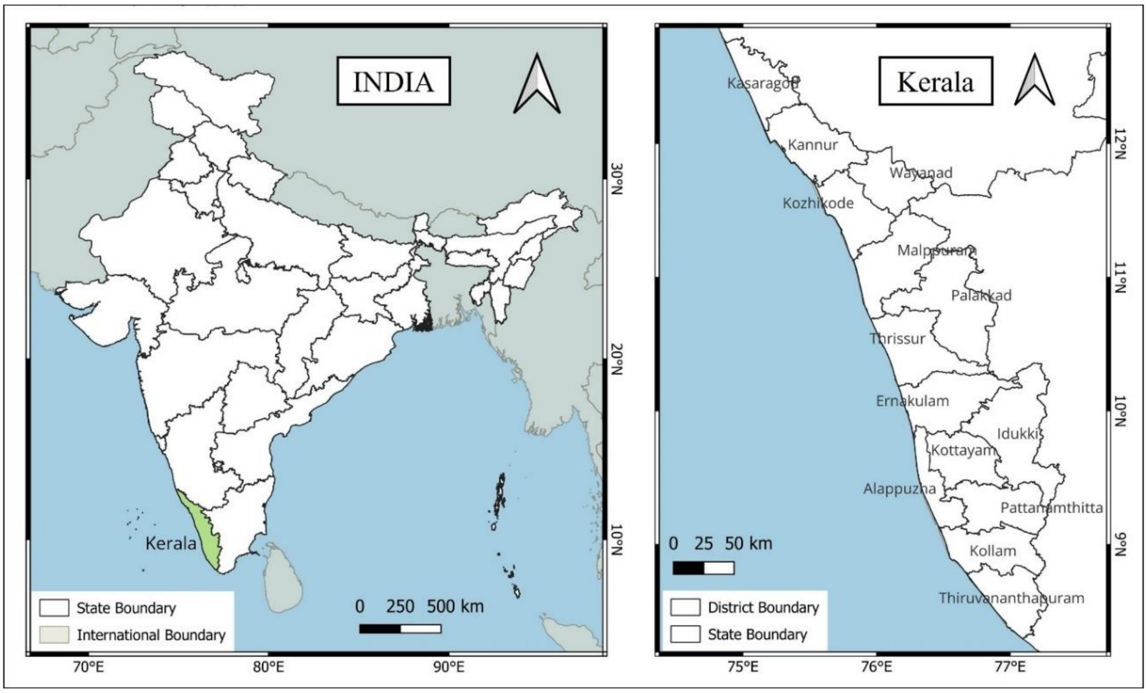

Fig 1: Kerala Administrative map

2.2 Statistical analysis

R Studio was used for statistical analysis of the epidemiological data. The following CRAN packages were used: "readxl" for importing MS excel files, "pdftools" and "stringr" for data extraction from pdfs, "tidyverse" for descriptive statistics, "TTR" for time series analysis, "stats" for regression analysis, “forecast” for forecasting and "ggplot" for graph plots.

A time series analysis using classical decomposition is done to understand various patterns and model the underlying components of a time series dataset. A time series includes trend (long-term variation in the series), seasonal (variation in the series at regular periods) and irregular/random (remainder after eliminating trend and seasonality of the series) components [11].

In an additive decomposition, where y_t is the data, S_t is the seasonal component, T_t is the trend-cycle component, and R_t is the remainder component, all at period t, is formulated as:

$$Y_t=S_t+T_t+R_t$$

The additive decomposition is suitable when the size of the seasonal fluctuations, or the deviation from the trend-cycle, remains consistent regardless of the time series level [12].

For forecasting the trend and capturing seasonality of Dengue incidence in the near future, exponential smoothing of the data is done using the Holt-Winters seasonal method. The additive method is preferred when the seasonal variations are roughly constant through the time series [12].

2.3 Geographical mapping

For the administrative map and choropleth map, the shapefile of India and Kerala with districts were downloaded from the online maps portal of Survey of India, Ministry of Science & Technology [13]. Maps were generated in QGIS software.

3. Results and Discussion

3.1 Exploratory data analysis

The first incidence of Dengue fever in Kerala was reported from Kottayam in 1997 [6]. Table 1 shows the annual Dengue fever incidence and mortality reported in Kerala from 1997 to 2022.

Table 1: Annual Dengue incidence and mortality reported in Kerala from 1997 to 2022

Year	Cases	Death	Year	Cases	Death	Year	Cases	Death
1997	14	4	2006	1019	5	2015	4114	29
1998	67	13	2007	657	11	2016	7218	21
1999	1	0	2008	733	3	2017	21993	165
2000	0	0	2009	1425	6	2018	4083	32
2001	70	1	2010	2597	17	2019	4669	21
2002	219	2	2011	1304	10	2020	2722	22
2003	3546	68	2012	4056	16	2021	3251	27
2004	686	8	2013	7938	29	2022	4468	58
2005	1028	7	2014	2548	13			

The above data is visualised as a dual-axis combo in chart Figure 2. The chart consists of two visual elements: a black bar chart representing the reported dengue fever incidence and a red line graph depicting the reported mortality, using the same yearly data from 1997 to 2022 in the X-axis.

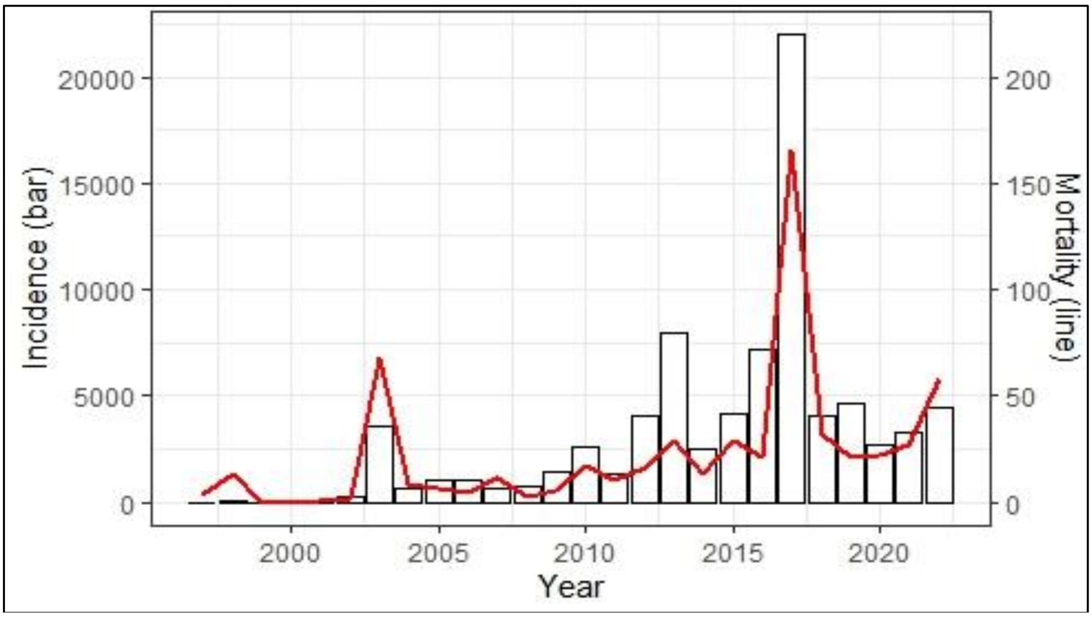

Fig 2: Dengue incidence and mortality reported annually in Kerala (1997-2022)

The bar plot depicts the reported incidence of Dengue fever in Kerala per year, ranging from 0 in 2000 to a peak of 21993 in 2017. From 2003, there was an interval of 3-4 years between the successive peaks of dengue incidence in Kerala. It is attributed to the super-annual cycle with a 3–4-year interval characteristic of the Dengue epidemic, which is determined by the intrinsic dynamics of Dengue and not by environmental factors [14]. The red line graph depicts the reported mortality from Dengue fever in Kerala per year, ranging from 0 in 1999 and 2000 to a peak of 165 in 2017.

The Government of India initiated the Integrated Disease Surveillance Project (IDSP) in November 2004 with support from the World Bank to have a decentralised state-based surveillance system for communicable diseases. District-wise annual incidence and mortality of various communicable and vector-borne diseases are available only from 2006, published by IDSP [8].

Table 2 presents the annual Dengue incidence reported in all Kerala districts from 2006 to 2022. Figure 3 illustrates this data as a line chart depicting the yearly Dengue incidence across all Kerala districts for the same time frame. Significant fluctuations in dengue incidence are evident yearly, with specific years exhibiting substantially higher cases than others. Additionally, the temporal trends in incidence within individual districts vary. Notably, Idukki experienced its highest peak in 2013, while Ernakulam recorded its peak in 2022, with most other districts reaching their peak in 2017. Kasaragod and Kottayam displayed multiple peaks.

Table 2: Annual Dengue incidence reported from all districts of Kerala from 2006 to 2022

District	2006	2007	2008	2009	2010	2011	2012	2013	2014
Kasaragod	13	8	6	48	342	12	99	176	45
Kannur	20	19	16	14	37	16	119	161	55
Wayanad	2	29	8	25	29	8	42	50	44
Kozhikode	13	44	25	11	47	38	44	167	276
Malappuram	5	8	7	13	18	21	163	523	146
Palakkad	26	6	7	19	14	17	108	152	40
Thrissur	72	89	10	152	74	28	173	229	153
Ernakulam	59	24	100	85	114	139	245	350	149
Idukki	17	22	5	20	169	13	86	369	20
Kottayam	8	7	20	160	330	62	156	412	30
Alappuzha	28	13	10	18	68	36	81	184	46
Pathanamthitta	19	28	4	34	144	15	143	484	191
Kollam	81	70	12	21	66	34	150	489	73
Thiruvananthapuram	656	290	503	805	1145	865	2447	4192	1280

District	2015	2016	2017	2018	2019	2020	2021	2022
Kasaragod	476	241	375	643	242	117	429	227
Kannur	156	98	629	338	212	268	116	110
Wayanad	157	223	463	48	177	49	32	88
Kozhikode	587	145	1354	247	405	69	209	44
Malappuram	275	248	963	877	361	60	169	267

Palakkad	145	136	2287	299	78	47	99	152
Thrissur	253	356	939	205	113	143	299	213
Ernakulam	243	431	494	177	431	295	945	1468
Idukki	127	125	168	53	87	38	74	21
Kottayam	98	543	429	125	166	226	139	68
Alappuzha	157	839	1375	149	355	221	110	281
Pathanamthitta	204	611	705	370	228	99	31	88
Kollam	245	1064	2857	248	696	460	114	597
Thiruvananthapuram	991	2158	8955	311	1100	631	485	844

Among the yearly maximum reported incidences, Thiruvananthapuram recorded the highest peak with 8955 cases in 2017, while in stark contrast, Idukki reported the lowest maximum annual incidence, registering only 369 cases in 2013. The district with the highest incidence did not remain constant throughout the entire study period. Till 2017, Thiruvananthapuram had the highest incidence every year. In 2018, Malappuram reported the highest incidence. In 2019 and 2020, Thiruvananthapuram reported the highest again, but in 2021 and 2022, Ernakulam reported the highest dengue incidence. The districts with the lowest incidence also exhibited fluctuations over time. Wayanad reported the lowest incidence for five years, followed by Idukki for four years, Palakkad for three years, Pathanamthitta for two years, and Kozhikode, Kottayam, and Kannur for one year. Wayanad, Idukki and Pathanamthitta are hilly region.

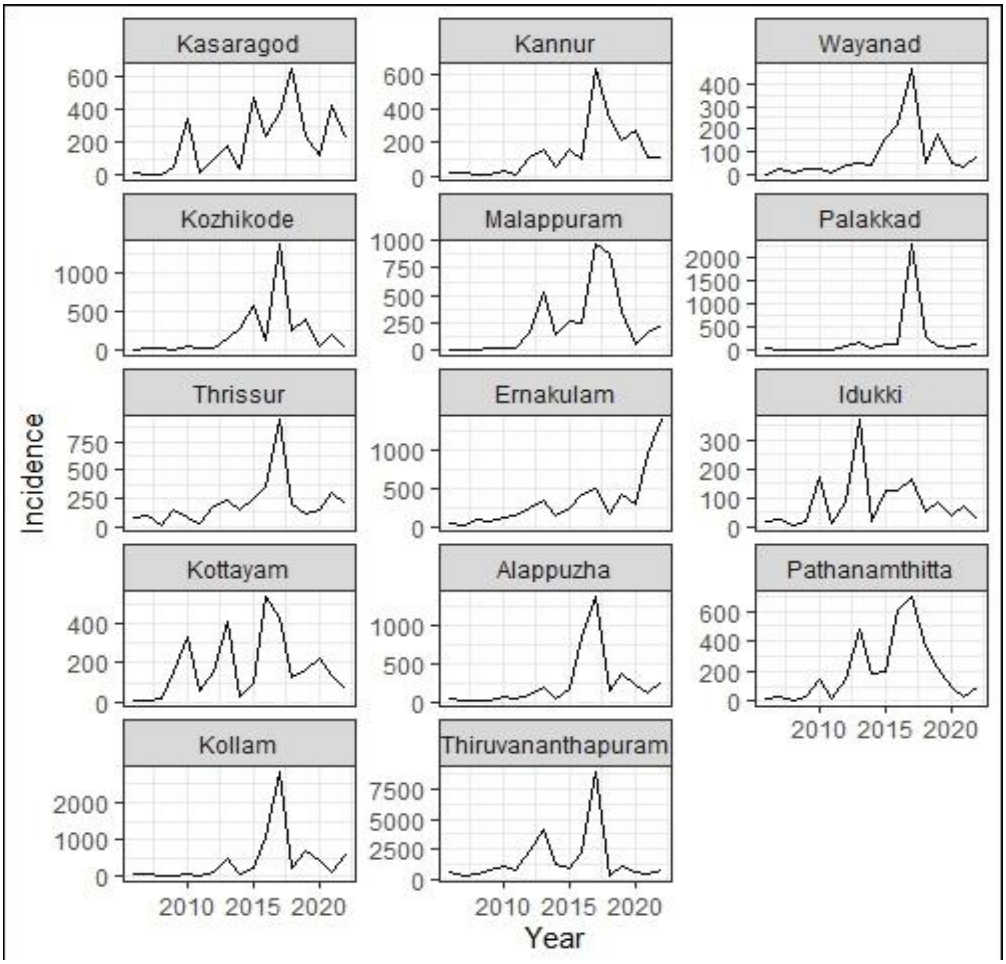

Fig 3: Annual Dengue incidences reported in all the districts of Kerala (2006-2022)

Figure 4 shows the Choropleth map of district-wise annual dengue incidence in Kerala from 2006 to 2022. Over time, there has been a rise in the incidence across all districts. Thiruvananthapuram consistently reported the highest incidence for most of the years, which is attributed to its status as the capital district and its densely populated area. This trend was followed by Ernakulam, a cosmopolitan city that surpassed Thiruvananthapuram in reported incidence in the past two years. The districts of Wayanad, Idukki, and Pathanamthitta, which are characterized by hilly terrain, consistently reported the highest proportion of the lowest annual incidence rates. From 2006 to 2009, Northern Kerala had annual incidences below 50. In 2015-2017 and 2019, all districts had more than 50 incidences per year. From 2010 to 2022, except for 2014 and 2021, all districts in southern Kerala reported more than 50 incidences per year. Since 2008, Ernakulam has consistently reported over 50 incidences annually, and since 2006, Thiruvananthapuram has never reported less than 100 incidences per year.

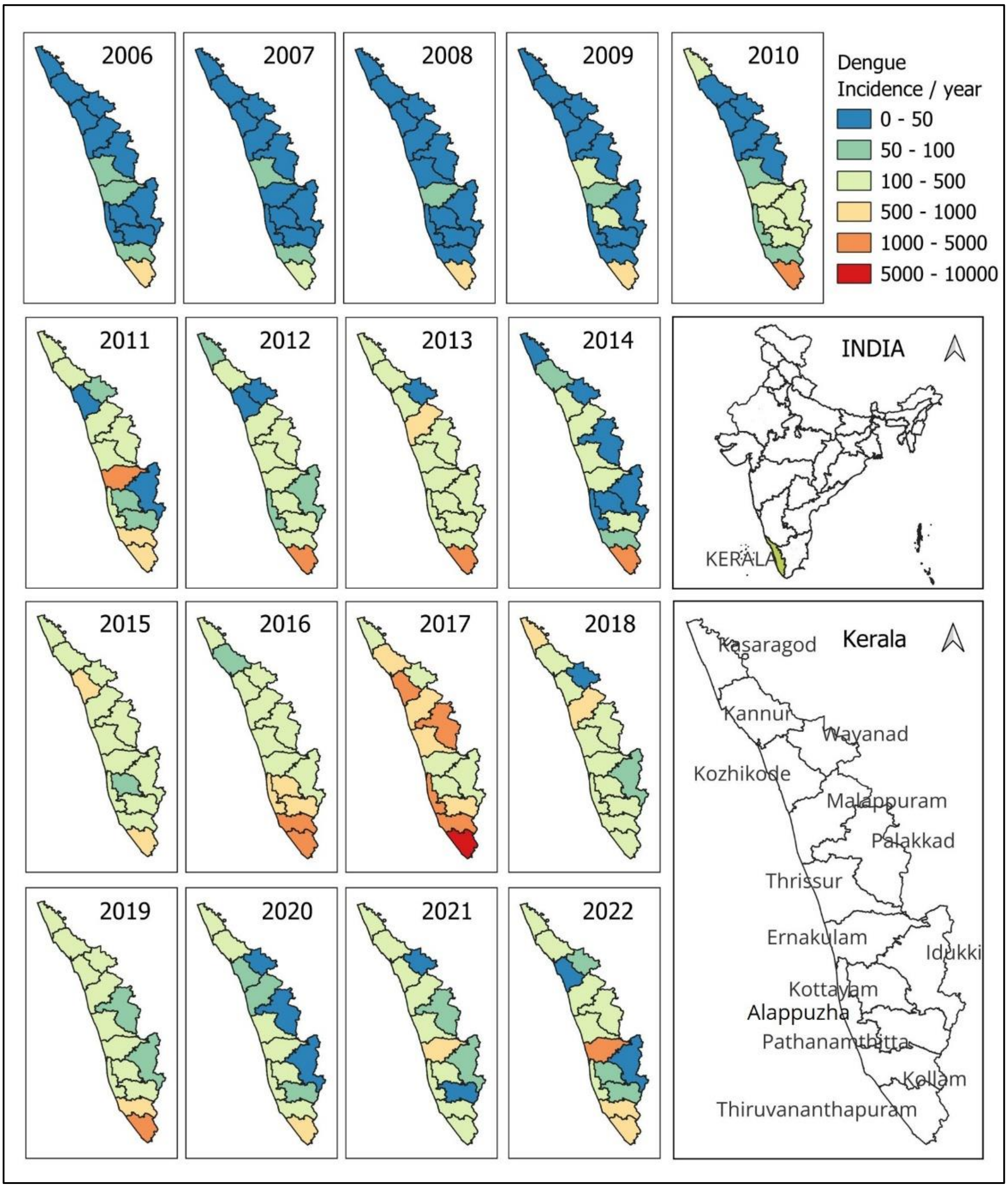

Fig 4: Choropleth map of district-wise annual Dengue incidence reported in Kerala (2006-2022)

Kerala, in 2017, experienced an unprecedented outbreak of Dengue fever, resulting in the largest morbidity and mortality, with 21993 cases and 165 deaths. These outbreaks, along with other mosquito-borne and water-borne diseases, prompted the Government of Kerala to establish a new policy, "Arogya Jagratha", to confront it. It was a part of Nava Kerala Mission, for fulfilling Sustainable Development Goals. It is a multi-departmental approach involving agencies of Aardam Mission (Health) and Harita Keralam Mission (Eco-friendly hygienic waste management). Its primary focus was on source reduction of vectors, vector control, and sensitisation about vector-borne diseases [15].

3.2 Time series analysis

Time series analysis using additive decomposition is used for trend identification, seasonal pattern detection, residual analysis, forecasting, and prediction. Table 3 shows Kerala's monthly dengue fever incidence from 2006 to 2022. Figure 5 depicts the decomposition of additive time series of monthly Dengue incidence in Kerala from 2006 to 2022.

Table 3: Monthly Dengue incidence in Kerala from 2006 to 2022

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	86	75	37	26	80	70	133	145	105	116	83	63
2007	44	23	10	7	40	143	145	94	64	29	29	29
2008	30	36	9	15	15	34	80	75	64	63	81	231
2009	208	146	60	73	86	183	196	191	116	88	47	31
2010	88	111	127	94	411	678	434	227	111	120	104	92

2011	68	41	54	53	84	168	129	146	115	188	116	142
2012	187	170	131	71	162	602	705	529	336	414	348	401
2013	344	170	186	451	1035	2161	1864	790	345	248	145	199
2014	103	72	68	65	131	352	404	358	240	304	233	218
2015	130	75	99	63	255	922	844	514	294	285	293	340
2016	241	318	200	222	639	1290	1264	1210	646	468	341	379
2017	415	301	473	1206	2621	5085	5555	3711	1187	696	426	317
2018	167	94	72	73	439	1454	779	293	282	181	135	114
2019	72	68	63	53	147	417	859	689	524	607	575	595
2020	443	201	92	76	322	709	453	153	54	63	71	86
2021	91	117	154	124	130	508	938	327	194	215	192	261
2022	169	95	133	168	343	627	644	492	392	414	523	466

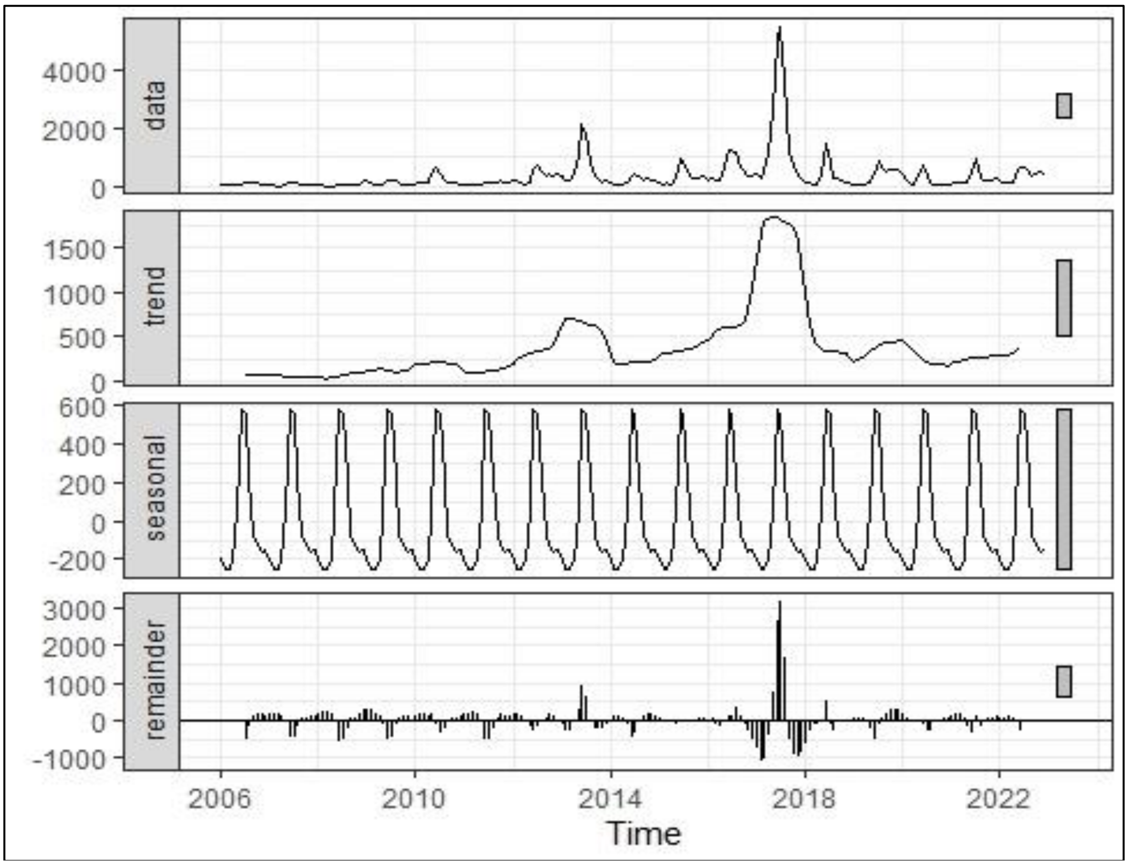

Fig 5: Decomposition of additive time series of monthly Dengue cases reported in Kerala from 2006 to 2022

3.2.1 Trend

The trend component is the long-term direction of the time series. The trend component of Dengue incidence per month is increasing slightly over time. This implies that, on average, the incidence of disease reported each month increases over time. Endemic transmission of dengue fever is typically distinguished by periodic outbreak cycles of around 3–4 years. The two main factors contributing to the outbreak cycles are: 1. Exhaustion of the susceptible population: after an outbreak, many people in the population will have been infected and developed immunity to the virus. This means fewer susceptible people are left in the population, and the virus will have a harder time spreading. 2. Short-term cross-immunity: People develop temporary immunity to the other three serotypes after being infected with one dengue serotype. However, this cross-immunity only lasts for a few months. After that, people are again susceptible to infection with all four serotypes [16]. A similar pattern is seen in Kerala, with peaks appearing in 2010, 2013, and 2017, implying the periodic outbreak cycle.

A linear regression model provides a statistical analysis of the relationship between the response variable and the predictor variable, namely Dengue cases reported monthly from 2006 to 2022 and time respectively. The regression model can be formulated as:

$$y = \beta 0 + \beta 1x + \varepsilon$$

Where y is the number of reported Dengue cases per month, x is time (measured in months), β0 is the intercept, β1 is the slope of the trend line, and ε is the random error term.

Table 4: A linear regression model between DE trended Dengue cases reported monthly from 2006 to 2022 and time

Call:				
Lm (formula = Trend ~ Date, data = Kerala Monthly Dengue Incidence)				
Coefficients				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1.02E+03	2.55E+02	-4.001	8.04e-05 ***
Date	8.59E-02	1.56E-02	5.491	1.25e-07 ***
Signif. codes:				
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
Residual standard error: 365.8 on 190 degrees of freedom				
Multiple R-squared: 0.1371, Adjusted R-squared: 0.1326				
F-statistic: 30.19 on 1 and 190 DF, p-value: 1.246e-07				

The coefficients table (Table 4) shows that the intercept (β0) is -1,022, which means that the predicted value of the dependent variable when the time variable is 0 is approximately -1,022. The slope of the regression line (β1) is 0.08597, which means that for each unit increase in the time variable i.e., month, the dependent variable's predicted value i.e., Dengue cases increases by approximately 0.08597 units. The residual standard error is 365.8, which is the estimate of the standard deviation of the error term (ε). This value represents the average error between the actual values of reported Dengue cases per month and the predicted values from the regression model. The multiple R-squared value is 0.1371, which means that only 13.71% of the variance in reported Dengue cases per month can be explained by the linear relationship with time. The adjusted R-squared value is 0.1326, which considers the number of variables in the model and adjusts for the sample size.

The low R-squared value suggests that other factors influence the variation in reported Dengue cases per month beyond the linear trend with time. The F-statistic of 30.19 tests the null hypothesis that all coefficients in the model are equal to zero. Furthermore, the p-value of 1.246e-07, which is less than 0.05, indicates that the model is statistically significant, which means that it is helpful in predicting future values of the time series data.

3.2.2 Seasonality

Seasonal decomposition reveals the periodic fluctuations or patterns that occur within each year or a known period. The seasonal component of Dengue incidence per month shows that incidences are typically higher in June-July. They form a bell starting from April, peak in June-July, then decline till September. Figure 6 shows Boxplot of monthly Dengue incidence in Kerala from 2006 to 2022 in both regular and Log_{10} scale. As the dataset has a wide range from 2 to 5555 cases, the Log_{10} scale is used to compress the scale and make the data more accessible to comprehend. The red dots are the mean values, which are highest during June - July. The boxes are broader during the peak of the bell, implicating a wide range of incidence.

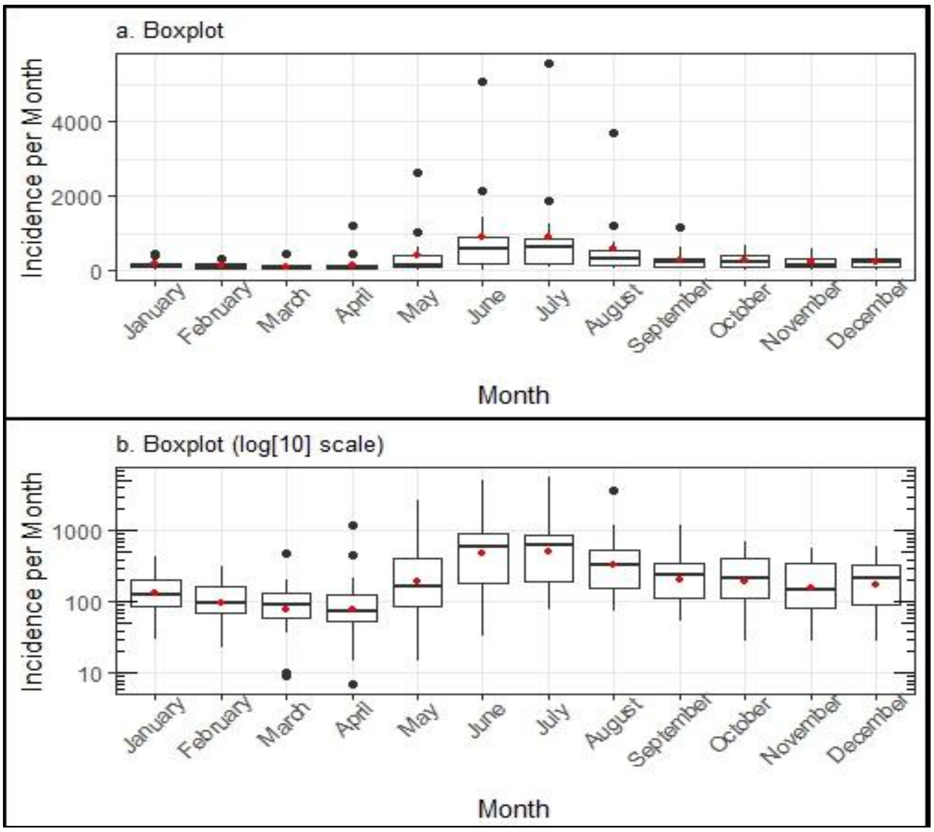

Fig 6: Boxplot of monthly Dengue incidence in Kerala from 2006 to 2022

As per the Indian Meteorological Department (IMD), the entire state of Kerala is classified as one meteorological sub-division for climatological purposes. The year may be divided into four seasons. The period from March to the end of May is the hot season. Pre-monsoon rainfalls occur during this season. This is followed by Southwest Monsoon season that continues till the beginning of October. From October to December is the Northeast Monsoon season. January and February are winter season assisted with winter Rainfall [17]. The Southwest monsoon provides ample habitat for the increase of Dengue vectors *Ae. Aegypti* and *Ae. Albopictus* leads to an increase in Dengue transmission and incidence. The rainfall also helps in the hatching of dormant *Aedes* eggs which may increase the chance of transovarian transmission of Dengue virus and cause Dengue outbreaks.

Figure 7 shows the detrended seasonal distribution plot of monthly Dengue incidence in Kerala from 2006 to 2022. The detrending process removes the long-term trend from the data, allowing focus on the seasonal component. The X-axis is the months, and the Y-axis is the Detrended seasonal component which scales the measure of the deviation from the average seasonal pattern, not the absolute number of incidences. The blue line is the median, and the light blue area is the 25%-75% of the incidences recorded. The horizontal dotted line is the average value of the detrended seasonal component. It is used as a reference line for comparing the seasonal components in different years.

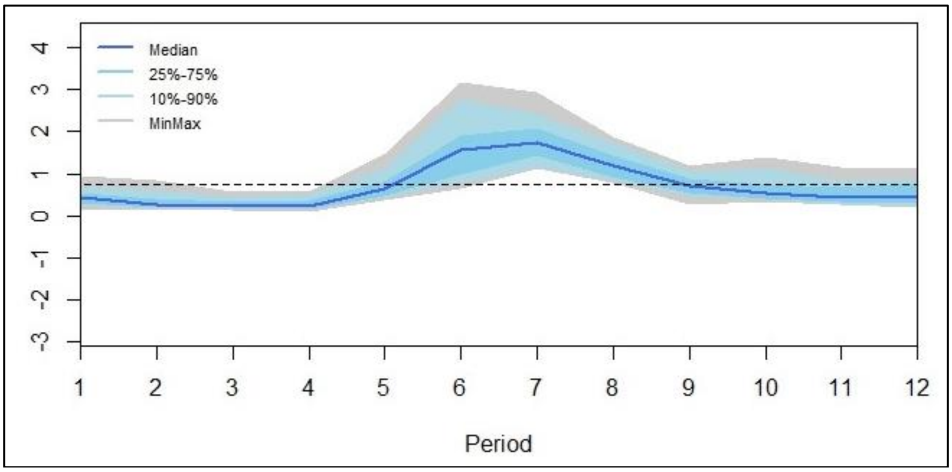

Fig 7: Seasonal distribution (Detrended) plot of monthly Dengue incidence in Kerala from 2006 to 2022.

3.3 Predictive analysis

Holt-Winters' additive method is used to forecast time series data exhibiting seasonality. It uses exponential smoothing to forecast the trend, seasonality, and residual components. Figure 8 provides the forecast for Dengue incidence till December 2024 based on the monthly incidence data from 2006 to 2022. It shows an increase in Dengue incidence in the coming years. The blue line is the point forecast, the light blue area shows the 95% confidence interval, and the grey area shows the 80% confidence interval. It forecasts the actual value of the time series at the next time step will fall within the interval.

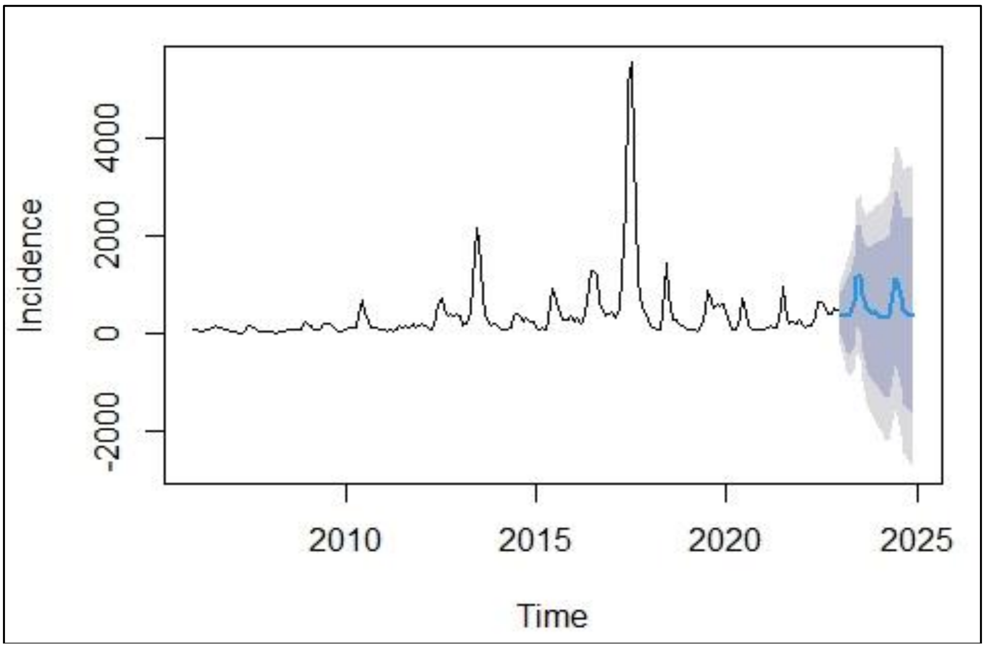

Fig 8: Forecast from Holt-Winters' additive method for the next 24 months from monthly Dengue incidence from Kerala (2006-2022)

4. Conclusion

Dengue fever has been added to the Neglected Tropical Diseases list by the World Health Organization (WHO), and its incidence has increased globally over the past two decades. A similar trend is observed in India, where dengue has been reported in 28 states and 7 UTs by 2022. In Kerala, dengue incidence increased from 14 in 1997 to 4432 in 2022. The increase in dengue incidence in Kerala has been gradual, with multiple peaks every 3-4 years, consistent with the periodic outbreak cycle of dengue fever. This suggests that dengue fever is endemic in Kerala.

The seasonal increase in dengue incidence during May-July coincides with the Southwest monsoon, providing favourable mosquito breeding conditions. Other factors contributing to Dengue fever's spread include geography, vegetation, population density, and urbanization. Thiruvananthapuram, the capital district with the highest population density, has always had the highest dengue incidence. In the past two years, Ernakulam, a highly urban cosmopolitan district, has overtaken Thiruvananthapuram regarding of dengue incidence. Wayanad and Idukki, hilly districts with low population density, have historically had the lowest dengue incidence.

Predictive analysis shows that dengue incidence in Kerala is likely to increase in the near future. This is a cause for concern, and health workers, the government, and the people must work together to control the spread of dengue fever.

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