

Trend Analysis and Forecasting of Dengue Incidence in India Using Exponential Models

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ABSTRACT

Background: Dengue fever remains a major public health concern in India, characterised by periodic outbreaks and fluctuating incidence rates. Reliable forecasting models are essential for planning preventive and control strategies.

Objective: To analyse the trend of dengue cases in India and to develop a suitable exponential smoothing model for forecasting future dengue incidence in India.

Methods: A retrospective time series analysis was conducted using yearly dengue case data of India from 2015 to 2025 obtained from the National Centre for Vector Borne Diseases Control (NCVBDC) under the Ministry of Health and Family Welfare, Government of India. The exponential models were used for forecasting dengue cases, which were estimated using maximum likelihood estimation and evaluated using Stationary R – squared, Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Bayesian Information Criterion (BIC).

Results: In this study, no seasonality was found; we used exponential smoothing, which is a time-series forecasting technique in which past observations are weighted exponentially, meaning that more recent values receive greater importance than older ones. This approach is particularly useful when the data show irregular fluctuations and when recent trends are more relevant for forecasting. From the exponential model's comparison, Holt's linear trend exponential smoothing shows the highest Stationary R-squared (0.704), lowest MAE (55,249), lowest RMSE (76,004) and lowest BIC (23.08). This indicates that Holt's linear trend exponential smoothing model captures both the level and trend better than the Simple, Brown, and Damped trend models. Hence, Holt's exponential model is the most suitable model for forecasting dengue cases in India.

Conclusion: The trend of dengue cases in India shows irregular yet increasing trends, particularly after 2020. Holt's Linear Exponential Smoothing model is most appropriate for short-term forecasting due to its ability to capture both level and trend components effectively.

Keywords: Dengue, Trend Analysis, Forecasting, Exponential Smoothing, India, Time Series

INTRODUCTION

Dengue fever, a mosquito-borne viral disease transmitted primarily by *Aedes aegypti*, has emerged as one of the most significant public health challenges in

tropical and subtropical regions worldwide. Over the past few decades, the global incidence of dengue has increased dramatically, with an estimated 390 million infections occurring annually [2]. In India,

dengue has become endemic in most states, with periodic epidemic outbreaks causing substantial morbidity and mortality [3]. The disease exhibits complex transmission dynamics influenced by multiple factors, including climatic conditions, urbanisation patterns, population density, vector control measures, and socioeconomic determinants. The temporal pattern of dengue incidence in India has demonstrated considerable variability, characterised by irregular fluctuations and unpredictable epidemic peaks. According to the National Centre for Vector Borne Diseases Control (NCVBDC), India has witnessed recurring outbreaks with varying intensity across different years, making it challenging to anticipate future disease burden and allocate resources effectively. The COVID-19 pandemic further complicated dengue surveillance and reporting systems, leading to apparent reductions in recorded cases during 2020, followed by a substantial resurgence in subsequent years [4,5]. These irregular patterns underscore the necessity for robust forecasting methodologies that can accommodate non-linear trends and adapt to rapidly changing epidemiological scenarios. Time series forecasting models have proven invaluable in epidemiological research, enabling public health authorities to anticipate disease trends, optimise resource allocation, and implement timely interventions. Among various forecasting approaches, exponential smoothing methods have gained widespread acceptance due to their simplicity, computational efficiency, and effectiveness in handling time series data with irregular patterns and limited observations [6]. Unlike more complex models that require extensive data and assume specific distributional properties, exponential smoothing techniques assign differential weights to historical observations, with recent data receiving greater emphasis and particularly relevant feature for dengue forecasting, where recent transmission dynamics may be more indicative of future trends than distant historical patterns.

Several studies have demonstrated the utility of exponential smoothing models in forecasting dengue incidence across different geographical contexts and successfully applied exponential smoothing to forecast dengue cases demonstrating the model's capacity to capture local transmission patterns [7]. Similar study employed time series analyses, including exponential smoothing, to forecast dengue incidence in Rajasthan, India, highlighting the model's applicability in the Indian epidemiological context [8]. More recent comparative studies have evaluated exponential smoothing against machine learning approaches, with findings indicating that traditional statistical methods remain competitive and often superior for short-term forecasting tasks, particularly when data limitations exist [9,10].

The present study addresses a critical gap in understanding dengue transmission dynamics in India by conducting a comprehensive trend analysis of national dengue incidence data spanning eleven years (2015–2025) and developing appropriate forecasting models using exponential smoothing techniques. Given the absence of clear seasonal patterns in the aggregated annual data and the presence of irregular fluctuations, we systematically evaluated four non-seasonal exponential smoothing models: Simple Exponential Smoothing, Holt's Linear Trend, Brown's Linear Trend, and Damped Trend Exponential Smoothing. Through rigorous statistical evaluation based on multiple performance metrics, including Stationary R – squared, Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Bayesian Information Criterion (BIC), we identified the Holt's Linear Trend is the most suitable model for forecasting future dengue burden in India.

This research contributes to the growing body of literature on dengue forecasting in South Asia and provides valuable insights for public health planning and resource allocation. By establishing a reliable forecasting framework tailored to India's

epidemiological context, this study aims to support evidence-based decision-making for dengue prevention and control strategies, ultimately contributing to reduced disease burden and improved public health outcomes.

Objectives:

To analyse the trend of dengue cases in India and to develop a suitable exponential smoothing model for forecasting future dengue incidence in India.

MATERIALS AND METHODS

Statistical Procedures:

Study Design and Data Source: This study employed a retrospective time series design using secondary data. Yearly dengue case data of India from 2015 to 2025 were obtained from the National Centre for Vector Borne Diseases Control (NCVBDC), Ministry of Health and Family Welfare, Government of India [1]. The statistical analyses were performed using IBM SPSS Statistics version 26 and $P < 0.05$ is considered as significant.

The following tests and methods were used in the study:

Time Series Plot:

A graph of values against time is usually used to extract meaningful characteristics of data. This graph can be used to study the patterns of data such as trends, seasonal, cyclic and irregular variations. In this study, no seasonality was observed, so we used non-seasonal exponential smoothing models.

Exponential Smoothing:

In exponential smoothing, recent observations are weighted more heavily than older observations and exponential models perform well with no clear seasonality, limited observations and irregular patterns.

There are four types of non-seasonal exponential smoothing models:

- **Simple Exponential Smoothing (SES):** The simplest of the exponential smoothing methods is called simple exponential smoothing (SES). The SES is suitable for modeling if the data do not represent a trend or seasonal pattern. The weight of each observation is determined by using a smoothing parameter.
- **Holt's Linear Trend (Double Exponential Smoothing):** This method is used when there is a linear trend in the data.
- **Brown's Linear Trend:** This model is appropriate for series in which there is a linear trend and no seasonality. Its smoothing parameters are level and trend, which are assumed to be equal.
- **Damped Trend Linear Exponential Smoothing:** It is an accurate benchmark forecasting method for data with trends that are unlikely to continue at a constant pace.

Model Building Criteria:

The non-seasonal exponential models were used for forecasting dengue cases, which were estimated using maximum likelihood estimation and evaluated using Stationary R – squared, Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Bayesian Information Criterion (BIC).

Forecasting:

The selected non-seasonal exponential model, Holt's linear trend exponential smoothing, was used to generate 5-years forecasts of dengue cases from 2026 to 2030. Forecasts were accompanied by 95% prediction intervals to account for uncertainty.

RESULTS

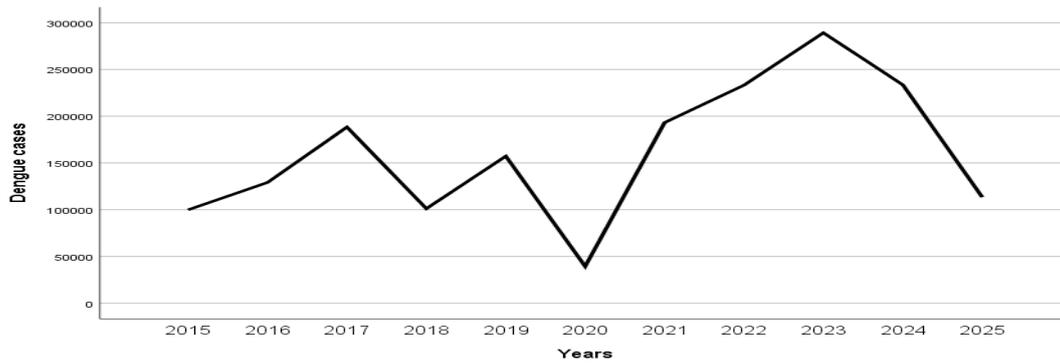


Figure No. 1: Trend of Dengue Cases in India (2015–2025)

The time series of dengue cases in India from 2015 to 2025 shows a highly fluctuating but overall increasing trend, rather than a smooth linear pattern. From 2015 to 2017, dengue cases increased sharply, indicating an outbreak phase. A decline is observed in 2018, followed by another rise in 2019. In 2020, cases dropped drastically, which can be attributed to COVID-19 lockdowns and reduced surveillance. From 2021 onwards, there is a strong resurgence with cases peaking in 2023, showing intensified transmission. A decline in 2024–2025 is observed, but the level remains higher than the pre-2020 period, indicating dengue has become more persistent. Overall, the series exhibits a non-linear trend, sudden rises and falls and no constant rate of increase or decrease in dengue cases in India.

Model Building Procedure:

We used an exponential trend model instead of a simple linear trend because exponential models perform well in the absence of clear

seasonality with limited observations and with irregular data patterns.

1. **Non-linear Growth Pattern:** The dengue cases do not increase at a constant rate. Exponential models are suitable when changes occur proportionally, not additively; recent observations have greater influence on future values. Exponential smoothing captures these rapid changes better than linear models.
2. **More Weight to Recent Years:** Dengue dynamics change quickly due to climate variability, vector control programs, and urbanisation. Exponential smoothing assigns higher weights to recent data, making forecasts more realistic for public health planning. Exponential models perform well with limited observations and irregular patterns. Exponential smoothing methods are widely used in public health forecasting due to their simplicity, robustness and good performance with short time series.

Table No. 1: Comparison and Selection of Exponential Smoothing Models:

Models	Stationary R ²	MAE	RMSE	BIC
Simple Exponential Smoothing	0.232	94,816	109,231	25.96
Holt's Linear Trend	0.704	55,249	76,004	23.08
Brown's Linear Trend	0.690	58,192	78,563	23.25
Damped Trend	0.318	82,537	99,918	25.43

In Table No.1, from the exponential model's comparison, Holt's exponential smoothing model shows a higher Stationary R-squared (0.704), lowest MAE (55,249), lowest BIC (23.08) and lowest RMSE (76,004). This indicates that Holt's model captures both the level and trend better than the Simple,

Brown, and Damped trend models. Hence, Holt's exponential model is the most appropriate for forecasting the future incidence of dengue cases in India.

Forecast Performance:

Table No.2: Five-Year Dengue Case Forecasting Values with 95% Prediction confidence Intervals for the Holt's Exponential Model

Years	Forecast values	Lower 95% CI	Upper 95% CI
2026	217,857	68,843	366,871
2027	227,695	54,258	401,132
2028	237,533	43,572	431,494
2029	247,371	34,986	459,756
2030	257,408	27,843	486,973

Table No. 2 shows that the five-year forecast generated using Holt's exponential smoothing model demonstrates a consistent upward trajectory in dengue incidence for the period 2026–2030. The projected values indicate a gradual annual increase in the

number of cases, reflecting the continuation of the historical trend observed in the time-series data. The 95% prediction confidence intervals widen over time, indicating growing uncertainty in long-term forecasts.

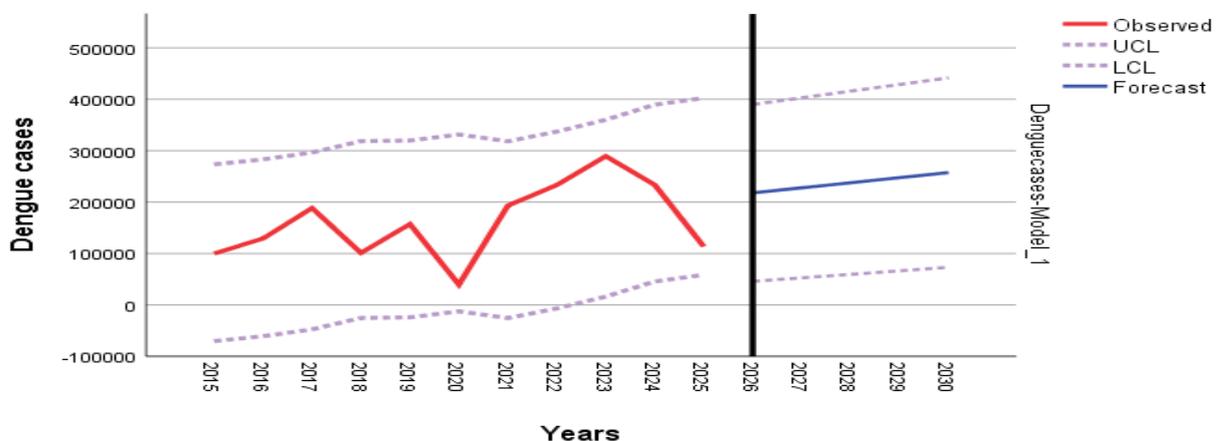


Figure 2: Observed vs. forecasted dengue cases for the year 2015 to 2025 with 95% confidence intervals

Figure 2 of the graphical representation further substantiates these findings by illustrating the alignment between observed and predicted values. The forecast line follows the general upward direction of the historical series, indicating that Holt’s model effectively captures the underlying trend component of dengue incidence. The confidence bands surrounding the forecast curve denote the plausible range of future observations and highlight the growing uncertainty with extended forecasting periods.

DISCUSSION

This study presents a comprehensive analysis of dengue trends in India from 2015 to 2025 and develops a forecasting framework using exponential smoothing models. Our findings reveal several important insights regarding dengue

transmission dynamics and demonstrate the effectiveness of Holt's Linear Trend Exponential Smoothing model for short-term forecasting of dengue cases in the Indian context. The observed temporal patterns, characterised by irregular fluctuations with an underlying increasing trend, reflect the complex interplay of factors influencing dengue transmission, including climatic variability, urbanisation, vector control interventions and healthcare-seeking behaviours.

Trend Analysis and Epidemiological Implications

The time series analysis revealed a non-linear growth pattern with substantial year-to-year variability, consistent with dengue epidemiology in other endemic regions of South and Southeast Asia. The sharp increase in cases from 2015 to 2017 likely

reflects a period of epidemic transmission, potentially driven by favourable climatic conditions and expanded surveillance efforts. The subsequent decline in 2018, followed by a resurgence in 2019, demonstrates the cyclical nature of dengue outbreaks, which has been documented extensively in the literature [4,11]. The dramatic reduction in reported cases during 2020 warrants particular attention, as it coincides with the COVID-19 pandemic and associated public health responses. Similar disruptions in dengue surveillance and reporting have been documented globally, with reporting comparable trends during the same period [5].

The post-2020 resurgence of dengue cases, with peak incidence observed in 2023, represents a concerning trend that has been observed across multiple countries in the Association of Southeast Asian Nations (ASEAN) region [11]. This pattern may reflect multiple contributing factors, including: (1) Relaxation of COVID-19-related movement restrictions leading to increased mosquito-human contact; (2) Accumulated susceptible population during the period of reduced transmission; (3) Potential changes in vector ecology and distribution and (4) Enhanced surveillance and reporting capacity. The persistence of elevated case numbers in 2024–2025, despite some decline from the 2023 peak, suggests that dengue has established a higher endemic baseline compared to the pre-pandemic period, necessitating sustained and intensified control efforts.

Model Selection and Performance Evaluation

The comparative evaluation of four non-seasonal exponential smoothing models demonstrated that Holt's Linear Trend model outperformed alternative approaches across multiple performance metrics. With a stationary R-squared of 0.704, this model explained approximately 70% of the variance in dengue incidence data, indicating a strong model fit. The lowest Mean Absolute Error (55,249 cases) and

Root Mean Square Error (76,004 cases) among all evaluated models further confirm the superior predictive accuracy of Holt's method. These findings align with previous research demonstrating the effectiveness of double exponential smoothing for infectious disease forecasting in contexts characterised by trending but non-seasonal patterns [7,8]. The superiority of Holt's model over Simple Exponential Smoothing (stationary R-squared: 0.232) can be attributed to its capacity to capture both level and trend components simultaneously. While Simple Exponential Smoothing is appropriate for stable time series without trends, the evident increasing trajectory of dengue cases in India necessitates a model that explicitly accounts for trend dynamics. Brown's Linear Trend model, although theoretically similar to Holt's method, demonstrated slightly inferior performance (stationary R-squared: 0.690), likely due to its constraint of equal smoothing parameters for level and trend components. This restriction may be overly simplistic for dengue data, where level and trend components evolve at different rates.

Interestingly, the Damped Trend model, which is often recommended for series with trends unlikely to continue indefinitely [12], showed relatively poor performance in our study (stationary R-squared: 0.318). This finding suggests that the damping parameter may have been overly conservative, potentially underestimating the persistence of the upward trend observed in recent years. The assumption underlying the damped trend model that the trend will eventually flatten or reverse may not be appropriate for dengue in India, where ongoing urbanisation, climate change, and evolving vector dynamics may sustain or even amplify transmission intensity in the foreseeable future.

Forecasting Results and Public Health Implications

The five-year forecast generated using Holt's Linear Trend model projects a continued increase in dengue incidence,

with predicted cases rising from approximately 217,857 in 2026 to 257,408 by 2030. These projections, while subject to considerable uncertainty as indicated by the widening 95% prediction intervals, provide valuable information for long-term public health planning. The forecast suggests that without substantial improvements in vector control, disease surveillance and community engagement, India may experience a sustained elevation in dengue burden over the coming years. This projection aligns with broader regional trends documented and reported increasing dengue incidence across ASEAN countries with similar epidemiological and environmental characteristics [11].

The widening prediction intervals in long-term forecasts reflect inherent uncertainties in dengue transmission dynamics, including unpredictable climatic events (e.g., extreme rainfall or drought), potential emergence of new dengue serotypes or strains, implementation of novel control interventions (such as Wolbachia-based vector control or dengue vaccines), and socioeconomic changes affecting mosquito breeding habitats. These uncertainties underscore the importance of interpreting forecasts as planning tools rather than definitive predictions. Public health authorities should use these projections to prepare for a range of scenarios, ensuring adequate resources, mobilisation for surveillance, laboratory capacity, clinical management and community-based prevention programs.

Comparison with Other Forecasting Approaches

Recent literature has increasingly explored machine learning and deep learning approaches for dengue forecasting, with some studies reporting superior performance compared to traditional statistical methods [9]. However, the choice between statistical and machine learning approaches should be guided by data availability, forecasting objectives and interpretability requirements. For the present study, exponential

smoothing was deemed most appropriate given: (1) The limited number of annual observations (11 years) (2) The absence of clear seasonal patterns in aggregated annual data (3) The need for interpretable models that public health practitioners can readily understand and implement and (4) The demonstrated effectiveness of exponential smoothing in similar contexts [7,10].

While machine learning methods may offer advantages when abundant data and complex predictor variables are available, they also require larger datasets for training, extensive computational resources, and specialised expertise for implementation and validation. The exponential smoothing approach adopted in this study offers a pragmatic balance between model simplicity and predictive accuracy, making it particularly suitable for resource-constrained settings where dengue surveillance systems may have limited analytical capacity. Furthermore, the transparency of exponential smoothing models facilitates communication of results to policymakers and stakeholders, enhancing the likelihood of forecast informed decision-making.

Strengths and Limitations

This study has several notable strengths. First, it utilises nationally representative data from the official surveillance system (NCVBDC), ensuring consistency in case definitions and reporting procedures. Second, the systematic comparison of multiple exponential smoothing models provides robust evidence for model selection, rather than relying on a single forecasting approach. Third, the study covers a recent 11-year period, including the COVID-19 pandemic, capturing contemporary dengue transmission patterns that reflect current epidemiological realities. Finally, the incorporation of 95% prediction intervals in forecasts appropriately acknowledges uncertainty and encouraging cautious interpretation of projections. However, several limitations warrant acknowledgement. The use of annual

aggregated data, while suitable for long-term trend analysis, precludes examination of seasonal patterns that are known to influence dengue transmission at sub-annual timescales. Monthly or weekly data would enable more granular forecasting and detection of seasonal epidemic peaks[10]. Additionally, the relatively short time series (11 observations) limits the complexity of models that can be reliably estimated and may reduce forecast precision. Ideally, longer time series spanning multiple decades would provide greater statistical power and enable detection of longer-term cycles or regime changes in dengue transmission.

Another important limitation concerns the potential influence of changing surveillance practices on reported case numbers. Improvements in diagnostic capacity, reporting systems, and healthcare access over time may contribute to apparent increases in dengue incidence that partially reflect enhanced case detection rather than solely increased transmission. The dramatic reduction in cases during 2020 likely reflects underreporting due to healthcare system disruptions rather than the genuine elimination of dengue transmission. These reporting artefacts complicate the interpretation of trends and may affect forecast accuracy. Future studies could benefit from incorporating adjustments for reporting completeness or using serological survey data to validate trends observed in surveillance systems.

Finally, the univariate nature of exponential smoothing models means that external predictors such as temperature, rainfall, humidity, population density, or intervention coverage are not explicitly incorporated. While exponential smoothing models may implicitly capture the effects of these factors to the extent they manifest in historical trends, multivariate approaches that explicitly model relationships between dengue incidence and environmental or sociodemographic covariates could potentially improve forecast accuracy and provide mechanistic insights. Future

research could explore hybrid approaches that combine the parsimony of exponential smoothing with the explanatory power of predictor variables.

Recommendations for Public Health

Practice

Based on the study findings, several recommendations emerge for dengue prevention and control in India:

The projected increase in dengue burden necessitates sustained investment in vector control programs, particularly integrated vector management strategies that combine source reduction, chemical control, biological control and community mobilisation.

Surveillance systems should be strengthened to ensure timely detection of emerging outbreaks and accurate characterisation of disease trends. Enhanced laboratory capacity for dengue serotype identification would enable monitoring of serotype circulation patterns, which have implications for disease severity and vaccine effectiveness.

Forecasting models should be integrated into routine surveillance operations to support early warning and proactive response planning. The exponential smoothing framework developed in this study could be implemented within existing surveillance platforms, with periodic model updates as new data become available.

Given the increasing trend in dengue incidence, healthcare systems must ensure adequate preparedness for epidemic surges, including stockpiling of diagnostic supplies, training healthcare workers in clinical management and establishing surge capacity protocols for intensive care units.

Research investments should continue to explore novel prevention technologies, including next-generation vaccines, innovative vector control methods and point-of-care diagnostics that can facilitate rapid case detection and appropriate clinical management.

CONCLUSION

This study provides comprehensive evidence that dengue trends in India exhibit irregular yet progressively increasing patterns. Among the evaluated models, Holt's Linear Exponential Smoothing model provided the most accurate short-term forecasts by effectively capturing both level and trend components. These findings support the adoption of exponential smoothing techniques for routine dengue surveillance and strategic public health planning.

Declaration by Authors

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Conflict of Interest: The authors declare no conflict of interest.

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