

Trend of HIV in India over a period of Time: A Time Series Approach

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ABSTRACT

This study investigates the trend of HIV in India over a period of time using time series analysis. Time series analysis helps organization understand the underlying causes trends patterns over time. In this case a statistical model is constructed on PLHIV (people living with HIV) and deaths due AIDS in India over a period of time. This model is based on dependent variable such as people living with HIV and people deaths due to AIDS and independent variable which is time period.

The purpose of the study is to build Time Series model using method of curve fitting by principal of least square which provide the future estimate of PLHIV (People living with HIV) and deaths due to AIDS. The data set from which model is built includes PLHIV(people living with HIV) and deaths due to AIDS from 2010-2021. Time series isolate and measure the effects of various components. From this model we will understand the past behaviour of the data and able to predict the future tendency of people getting affected and the pattern of deaths of HIV patients.

KEYWORDS: HIV Trends, AIDS Mortality, People Living with HIV (PLHIV), Time Series Analysis, Quadratic Trend Model, Forecasting, Least Squares Method

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INTRODUCTION

HIV (Human Immunodeficiency Virus) and AIDS (Acquired Immunodeficiency Syndrome) remain significant global public health issues. HIV is a virus that attacks the body's immune system. AIDS is the final stage of HIV infection, characterized by a severely weakened immune system, which increases vulnerability to opportunistic infections and certain cancers. Although there is no cure for HIV, effective antiretroviral therapy (ART) can control the virus and help prevent transmission, enabling individuals to live long and healthy lives.

India faces a significant HIV/AIDS public health challenge, with a concentrated epidemic affecting approximately 2.1-2.5 million people and a national prevalence of 0.26-0.36% (H. Pandve et al., 2015; R. Paranjape et al., 2016; Y. Marfatia et al., 2007). The epidemic is characterized by low general population rates but high concentrations among specific risk groups, including sex workers (up to 7% prevalence), with heterosexual transmission being the primary driver (R. Paranjape et al., 2016). While new infections peaked in 1998 and have since declined by 60%, the total HIV-positive population remains stable, likely due to increased life expectancy from antiretroviral therapy (R. Paranjape et al., 2016). Globally, HIV has claimed over 39 million lives, with 1.5 million deaths in 2013 alone, underscoring the ongoing public health challenge (H. Pandve et al., 2015).

Monitoring temporal trends in PLHIV and AIDS deaths is critical because it enables targeted health policy development, reveals epidemiological shifts, and guides resource allocation for prevention and treatment strategies. The evidence is robust and multi-dimensional. (Elisangela Mascarenhas da Silva et al., 2025) demonstrate that tracking trends reveals critical regional variations, highlighting the need to "plan health policies and reorganize specialized services" based on local epidemiological profiles. (R. Granich et al., 2015) showed that expanded treatment monitoring could avert millions of premature deaths, with countries like South Africa potentially preventing 2.2 million deaths by improving tracking and intervention. (A. T. Boyd et al., 2020) further emphasize the importance by introducing systematic mortality tracking indicators, while (R. Sekar et al., 2016) confirm the global impact, showing how monitoring helped reduce AIDS-related deaths from 2.4 million in 2005 to 1.2 million in 2014.

India's HIV epidemic remains concentrated, with national adult HIV prevalence declining from 0.26% in 2015 to 0.22% in 2017, affecting approximately 2.1 million people (A. Pandey et al., 2017)(M. V. Vardhana Rao et al., 2020). The National AIDS Control Programme (NACP) has made significant progress, with key achievements including: 32% decline in new HIV infections from 2007 to 2015, 54% reduction in AIDS-related deaths during the same period; focused interventions for high-risk populations like men who have sex with men, people who inject drugs, and female sex workers (Sukarna S. S. Tanwar et al., 2016). Key populations remain at highest risk, with transmission rates 20-30 times higher than the general population (Riya Palchaudhuri et al., 2016). While national trends show improvement, some states like Assam, Gujarat, and Uttar Pradesh still show increasing HIV incidence (A. Pandey et al., 2017).

Dementia trends show a complex picture of stable to declining prevalence and incidence, particularly in high-income countries, with significant geographical variations. The evidence from multiple studies indicates nuanced trends: (B. Stephan et al., 2018) found that prevalence rates are largely increasing in Japan, Canada, and France, but have remained stable in Sweden, Spain, and China. Notably, a significant decline in prevalence has been reported in recent studies (post-2010) from Europe and the USA. Incidence rates have generally remained stable or decreased across multiple countries including China, Canada, France, Germany, Denmark, Sweden, the Netherlands, UK, and USA. Only five countries (Italy, Japan, Wales, Germany, and the Netherlands) reported an increase (B. Stephan et al., 2018). M. Prince et al., (2016) corroborates these findings, suggesting some moderately consistent evidence of declining dementia incidence in high-income countries, though with remaining uncertainty about future epidemic scales.

Objective of the study is;

- To model the trend of PLHIV in India from 2010–2021 using a quadratic time-series trend model.
- To model the trend of deaths due to AIDS over the same period using a quadratic trend.
- To generate short-term forecasts that can inform policy discussions.

LITERATURE REVIEW

HIV/AIDS remains a significant global public health challenge, with approximately 38 million people currently living with the virus, predominantly concentrated in sub-Saharan Africa (Wairimu G. Mwendu et al., 2024; Dr Sashini Payagala et al., 2024). In 2019, there were 36.85 million cases, resulting in 863,840 deaths and 47.63 million disability-adjusted life years (DALYs) (Xuebin Tian et al., 2023). The epidemic's burden is not uniformly distributed: high age-standardized rates are predominant in low sociodemographic index areas, particularly Southern Sub-Saharan Africa (Xuebin Tian et al., 2023). Despite progress in treatment and prevention, significant challenges persist, including stigma, unequal healthcare access, and the need for comprehensive prevention strategies (Dr Sashini Payagala et al., 2024). The global community aims to end AIDS by 2030, requiring sustained social mobilization and targeted interventions (P. Piot et al., 2001).

The global HIV epidemic is transitioning from high to moderate prevalence, characterized by stabilization and selective decline across different populations and regions. The global HIV prevalence has stabilized at 0.8%, with 35.3 million people living with HIV in 2012 (Jade Fettig et al., 2014). Epidemiological evidence shows declining infection rates in some regions, particularly in general populations, while remaining high in key populations (C. Beyrer et al., 2013). Critical nuances include declining epidemics in general populations, persistent high prevalence among men who have sex with men (MSM), injecting drug users, and in specific regions like Eastern Europe, and increased prevalence partly driven by longer survival due to antiretroviral treatments. The transition is uneven, with significant regional variations and continued challenges in addressing HIV among marginalized populations (P. Kilmarx et al., 2009).

The global HIV epidemic shows a complex pattern of stabilizing prevalence, declining mortality, but persistent new infections worldwide. Key epidemiological trends include: global HIV prevalence has stabilized around 0.8-0.5% of the population (R. Govender et al., 2021)(P. Kilmarx et al., 2009), with approximately 35.3 million people living with HIV by 2012 (Jade Fettig et al., 2014). Global HIV incidence peaked in 1997 at 3.3 million new infections and has since remained relatively constant at about 2.6 million annually (Huan He et al., 2022). Mortality rates are declining, currently at 11 deaths per 100,000 population and projected to decrease to 8.5 deaths by 2040 (R. Govender et al., 2021). However, significant regional variations exist, with rising infection rates in regions like Russia, Ukraine, and the United States (R. Govender et al., 2021).

The United States had approximately 1.1 million adults and adolescents living with HIV in 2008, with a national prevalence rate of 0.447% per 100,000 population. The evidence comes from two robust sources: ("HIV in the United States : An Overview") reported 1,178,350 PLHIV in 2008, while ("HIV prevalence estimates--United States, 2006.") estimated 1.1 million adults with an HIV prevalence rate of 447.8 per 100,000. For comparative context, (A. Pandey et al., 2009) estimated 2.47 million PLHIV in India in 2006, with a national adult HIV prevalence of 0.36%. (M. V. Vardhana Rao et al., 2020) later refined this to 2.1 million PLHIV in 2017, with prevalence declining to 0.22%. These estimates demonstrate the ongoing challenge of HIV, with significant variations in prevalence across different national contexts.

The HIV situation varies dramatically across India's states, with highest prevalence in Nagaland, Mizoram, Manipur, Andhra Pradesh, and Karnataka (V. Ojha et al., 2006). While the national infection rate is low, certain populations face dramatically higher risks: men who have sex with men and people who inject drugs are 20-30 times more likely to be infected compared to the general population (Riya Palchaudhuri et al., 2016). Regional trends show declining infections nationally (32% reduction since 2007), but some states like Assam, Chhattisgarh, and Uttar Pradesh are experiencing increasing HIV rates (A. Pandey et al., 2017). Key affected populations include sex workers (2.8% HIV prevalence), transgender individuals, and mobile populations, with sexual transmission accounting for 85.3% of infections (Shaukat Mohammed et al., 2003; R. Paranjape et al., 2016).

India's National AIDS Control Programme (NACP) has successfully halted and reversed the HIV epidemic through comprehensive, targeted interventions across multiple program phases. The program has made significant strides: (Sukarma S. S. Tanwar et al., 2016) reports scaling up prevention, testing, and treatment services nationwide, which not only stopped the epidemic's spread but also dramatically reduced AIDS-related annual deaths. (Anubhuti Joshi et al., 2023) notes the current NACP-IV aims to diagnose and reduce new HIV cases by 50%, focusing on decentralized responses and key affected populations. Key achievements include; developing innovative prevention strategies for high-risk groups, providing free antiretroviral therapy,

expanding from a centralized to a district-driven approach and increasing NGO and PLHIV network involvement. Challenges remain in ensuring service quality, sustainability, and reaching rural populations (A. Kadri et al., 2012), but the overall trajectory demonstrates substantial progress in controlling HIV/AIDS in India.

India's HIV epidemic shows a nuanced picture of decline in new infections and mortality, coupled with a persistent disease burden. New HIV infections have decreased by approximately 32% from 2007 to 2015 (A. Pandey et al., 2017), with AIDS-related deaths declining by 54% in the same period. However, the total number of people living with HIV remains stable at around 2.1 million (R. Paranjape et al., 2016). Notably, the decline is not uniform across India. While most states show decreasing trends, some regions like Assam, Chhattisgarh, and Uttar Pradesh have experienced increasing HIV incidence (A. Pandey et al., 2017). The national adult HIV prevalence remains low at 0.26%, but certain high-risk groups still face significantly higher rates (R. Paranjape et al., 2016). Recent data even suggests that despite the COVID-19 pandemic, HIV/AIDS deaths continued to decrease, dropping by 28.82% annually from 2019-2021 (Karan Varshney et al., 2024).

Trend analysis is critical for informing HIV public health policy by providing data-driven insights into epidemic dynamics, intervention effectiveness, and resource allocation strategies. Evidence from multiple studies demonstrates the robust utility of trend analysis. (G. Rutherford et al., 2010) developed a 12-step triangulation process for synthesizing secondary data to understand HIV transmission dynamics. (G. Ryan et al., 2014) showed that trend analysis can help agencies compare intervention strategies across thousands of simulated scenarios, revealing that treatment initiation and adherence interventions were most likely to achieve policy objectives. J. Stover et al. (2011), further validated this approach, highlighting how mathematical modeling provides critical information for policy development in areas like male circumcision, antiretroviral therapy prevention, and emerging prevention technologies. The strength of evidence spans multiple methodological approaches and regional contexts, underscoring trend analysis as a fundamental tool in HIV public health decision-making.

Early detection and disease surveillance are critically valuable for HIV management, offering significant economic savings and potential reduction in transmission. Multiple studies demonstrate the importance of early HIV detection. (V. Zah et al., 2015) found projected cumulative cost savings of £21.6 million over 5 years in the UK through early detection, with savings directly proportional to the shift from late to early detection. (P. Sullivan et al., 2007) noted that modern surveillance systems now focus on earlier events in HIV infection, tracking behaviors, incident infections, and first diagnoses.

(M. Smith et al., 2013) emphasized that early detection is epidemiologically critical because individuals are most contagious during early infection. (Augustine S. Mbitila et al., 2012) confirmed through modeling that case detection can positively impact epidemic transmission, though early detection alone is insufficient to eliminate the disease. The evidence suggests early detection is a key strategy in HIV management, offering economic benefits and potential transmission reduction.

Although extensive research has documented the epidemiological burden of HIV globally and in India, most studies remain predominantly descriptive and do not provide predictive modelling to forecast the future course of the epidemic. Prior research typically evaluates prevalence or mortality separately rather than jointly analysing PLHIV and AIDS-related deaths. Furthermore, commonly used forecasting approaches rely on ARIMA, exponential, or regression-based modelling, with limited application of quadratic trend modelling despite its suitability for non-linear epidemic patterns. In addition, the annual NACO dataset from 2010 to 2021—one of the most comprehensive national HIV surveillance datasets—has not been utilised for predictive purposes. Thus, there is a clear gap for a study that simultaneously models and forecasts PLHIV and AIDS-related deaths in India using a quadratic time-series framework to provide short-term estimates for evidence-based policy planning.

In summary, while existing literature extensively documents the epidemiological patterns of HIV in India, it lacks predictive, data-driven evidence that can inform short-term policy and resource allocation. Few studies employ time-series forecasting, and none jointly analyse PLHIV and mortality trends using annual NACO data. This study fills these gaps by applying a quadratic time-series model based on the principle of least squares to develop forecasts for both PLHIV and AIDS-related deaths, offering actionable insights for public health planning.

METHODOLOGY

2.1. Data Selection

At first, the relevant data set from which the model would be built need to be selected. In this case, the data source is National AIDS Control Organization (NACO). This data base allows a registered user to fetch the data based on PLHIV (people living with HIV) and deaths due to AIDS over a period of time. This data set provides annual data from 2010 to 2021.

2.2. Variable Selection

The variables under study were examined to establish whether that capture both the time-dependent nature of the data and any other factors that may influence the HIV trends. The data set include independent variable i.e, time period from 2010 to 2021. and dependent variables are the number of HIV cases and number of deaths due to AIDS.

2.3. Exploratory Data Analysis

To construct the model, exploratory data analysis is basic step to perform. The section includes examining descriptive statistics and possible relationship between the independent variables. Here the descriptive statistics part includes the measure of central tendency (mean) and measure of dispersion (i.e. standard deviation). In this case, a sample size n is taken. So, to compute sample mean The mean (or average) of a set of values $X_1, X_2, X_3, \dots, X_n$ is given by the formula:

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n x_i$$

The formula for the sample standard deviation of a set of values $X_1, X_2, X_3, \dots, X_n$ is given by:

$$s = \frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2$$

- \bar{X} is the mean of the set of values.
- n is the sample size.
- X_i represents each individual value in the set.
- s is the sample standard deviation.

2.4. Method of Least Squares

Method of least squares a device for finding the equation of a specific type of curve, which best fits a given set of observation. The method depends upon the *principle least squares*, which suggests that for the "the best fitting" curve, **the sum of the squares of differences** between the observed and the corresponding estimated values should be the minimum possible.

$$E = (y_i - Y_i)^2$$

2.5. Estimation of the Model Parameters

The estimation of parameters of the model using least square involves fitting a non linear trend equation that are used to minimize the sum of the squared difference between the observed values and the values predicted by the model.

$$Y = a + bt + ct^2 \text{ where } a, b, c \text{ are parameters}$$

The normal equations are

$$\sum_{i=1}^n y_i = na + b \sum_{i=1}^n t_i + c \sum_{i=1}^n t_i^2$$

$$\sum_{i=1}^n y_i t_i = a \sum_{i=1}^n t_i + b \sum_{i=1}^n t_i^2 + c \sum_{i=1}^n t_i^3$$

$$\sum_{i=1}^n y_i t_i^2 = a \sum_{i=1}^n t_i^2 + b \sum_{i=1}^n t_i^3 + c \sum_{i=1}^n t_i^4$$

Solving the above normal equations the values of a, b, c are determined.

RESULTS & DISCUSSION

3.1. Exploratory Data Analysis:

An exploratory data analysis is carried out which includes descriptive statistics and line diagram over a period of 12 years.

Table 1: descriptive table of PLHIV (people living with HIV)

	N	Minimum	Maximum	Mean	Std.Deviation	Variance
PLHIV	12	23,90,000	27,00,000	24,91,000	108337	11740000000
Valid N (list wise)	12					

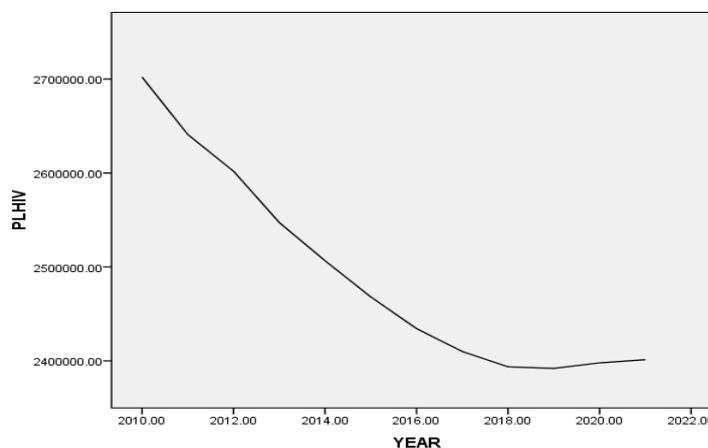


Figure 1: line graph of PLHIV(people living with HIV) over past 12 years

From the above data analysis, it is seen that the people living with HIV are gradually decreasing year by year. But the average number of people affected by HIV is nearly 24,91,000 every year with standard deviation 108337.

Table 2: descriptive table of deaths due to AIDS

	N	Minimum	Maximum	Mean	Std.Deviation	Variance
deaths	12	68	406	198.17	108.17060	11700
Valid N (list wise)	12					

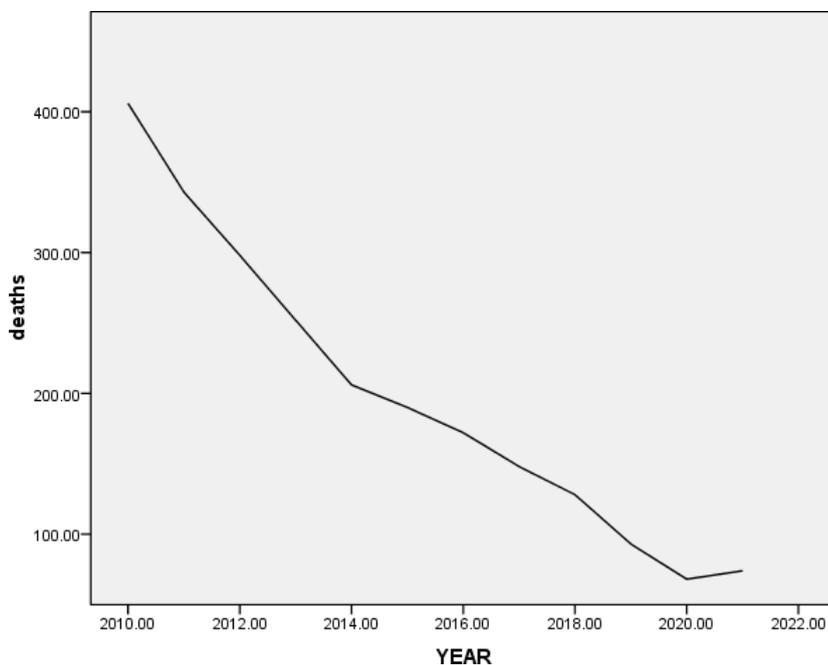


Figure 2: line graph of deaths due to AIDS over past 12 years

From the above analysis it is seen that the number of deaths occurred due to HIV are gradually decreasing year by year. But the average number of people died due to HIV is nearly 198 every year with standard deviation 108.1706.

3.2. Model Summary

To predict the future tendency of number of people living with HIV and number of deaths due to HIV two quadratic trend equations are constructed in both these two cases.

The given table is model summary table which provides the values of $y, yt, yt^2, t, t^2, t^3, t^4$ over a period of years. Moreover this table provide total number of people having HIV over past 12 years.

Table 3: PLHIV(people living with HIV) in year 2010-2021

YEAR	No. of PLHIV(y)	t	t^2	t^3	t^4	yt	yt^2
2010	2702171	-11	121	-1331	14641	-29723881	36962691
2011	2641018	-9	81	-729	6561	-23769162	213922458
2012	2601916	-7	49	-343	2401	-18213412	127493884
2013	2547307	-5	25	-125	625	-12736535	63682675
2014	2506608	-3	9	-27	81	-7519824	22559472
2015	2468079	-1	1	-1	1	-2468079	2468079
2016	2434353	1	1	1	1	2434353	2434353
2017	2409965	3	9	27	81	7229895	21689685
2018	2393672	5	25	125	625	11968360	59841800
2019	2392008	7	49	343	2401	16744056	117208392

2020	2397884	9	81	729	6561	21580956	194228604
2021	2401284	11	121	1331	14641	26414124	290555364
Total	29896265	0	523	0	48620	-8059149	1443047457

The normal equations of this quadratic model is given as follows

$$29896265 = 12a + 523b \dots\dots\dots(1)$$

$$-8059149 = 523b \dots\dots\dots(2)$$

$$1443047457 = 523a + 48620c \dots\dots\dots(3)$$

Solving the equations (1), (2) and (3) we get,

$$\hat{a} = 2255739.5, \hat{b} = 15409.5, \hat{c} = 5406.1$$

The predictive time series model of quadratic trend of PLHIV(people living with HIV) is

$$y = 2255739.5 - 15409.5t + 5406.1 t^2$$

The following table is model summary table which is related to total number of deaths due to AIDS over past 12 years.

Table 4: no. of deaths due to AIDS in year 2010-2021

YEAR	No.of deaths(y)	t	t ²	t ³	t ⁴	yt	yt ²
2010	406	-11	121	-1331	14641	-4466	49126
2011	343	-9	81	-729	6561	-3087	27783
2012	298	-7	49	-343	2401	-2086	14602
2013	252	-5	25	-125	625	-1260	6300
2014	206	-3	9	-27	81	-618	1854
2015	190	-1	1	-1	1	-190	190
2016	172	1	1	1	1	172	172
2017	148	3	9	27	81	444	1332
2018	128	5	25	125	625	640	3200
2019	93	7	49	343	2401	651	4557
2020	69	9	81	729	6561	621	5589
2021	74	11	121	1331	14641	814	8954
Total	2379	0	523	0	48620	-8365	123659

The normal equations of this quadratic model is given as follows

$$2379 = 12a + 523b \dots\dots\dots(4)$$

$$-8365 = 523b \dots\dots\dots(5)$$

$$123659 = 523a + 48620c \dots\dots\dots(6)$$

Solving the equations (4), (5) and (6) we get,

$$\hat{a} = 164.7, \hat{b} = -15.9, \hat{c} = 0.77$$

The predictive time series model of quadratic trend of number of deaths occurred due to HIV is

$$y = 164.7 - 15.9t + 0.77 t^2$$

Implications for Policy

The forecasting results of this study have crucial implications for public health planning in India. First, the projected decline in AIDS-related mortality demonstrates the effectiveness of antiretroviral therapy expansion and suggests the necessity of continued investment in treatment adherence initiatives. Second, even though PLHIV levels are decreasing, the estimates indicate that the number of people living with HIV will continue to remain significantly high over time. This highlights the need to sustain resources for long-term treatment, counselling, and psychosocial support rather than shifting attention away from HIV programmes. Third, the predictive trends can assist policymakers in estimating future demand for HIV testing kits, ART drug procurement, human resources, and treatment infrastructure in advance. Finally, the results can contribute to evidence-based intervention strategies for key populations and high-burden states by enabling more accurate and timely allocation of resources. Thus, integrating time-series forecasts into programme planning may enhance the efficiency and sustainability of the National AIDS Control Programme.

Limitations of the Study

While this study provides valuable insights, certain limitations should be acknowledged. The model uses national-level aggregated data, which masks state-wise heterogeneity and may overlook regional variations in HIV burden. The use of quadratic trend modelling assumes a smooth non-linear pattern of disease progression, which may not fully capture sudden changes caused

by behavioural, social, or epidemiological shocks such as pandemics, migration patterns, or changes in prevention strategies. The forecasting is based solely on historical PLHIV and mortality data without accounting for additional explanatory determinants such as socioeconomic variables, ART coverage, testing uptake, or risk-group dynamics. Furthermore, only 12 years of annual data were available, which restricts the precision of long-term trend forecasting. Therefore, the projections should be interpreted as indicative estimates rather than definitive predictions.

Scope for Future Research

Future studies can strengthen the understanding of HIV trends in several ways. Incorporating advanced forecasting methodologies—such as ARIMA, exponential smoothing, machine learning algorithms, or hybrid models—may improve the accuracy of projections. Disaggregating the analysis to state or district levels would allow identification of high-risk clusters and support targeted interventions. Further research could include additional predictor variables such as ART coverage, demographic characteristics, socioeconomic indicators, stigma levels, and high-risk behavioural patterns to enhance the explanatory power of predictive models. Longitudinal modelling of key population groups, including MSM, FSW, IDU, and transgender individuals, can also reveal important insights into transmission dynamics. In addition, integrating HIV forecasts with healthcare cost models could support financial planning and resource mobilisation for HIV elimination goals. Such research will deepen evidence-based decision-making and support India's progress toward achieving the UNAIDS 95-95-95 targets.

CONCLUSION

The present study modelled the temporal trends of HIV in India by analysing annual data on people living with HIV (PLHIV) and deaths due to AIDS from 2010 to 2021 using a quadratic time-series approach. The findings clearly indicate a gradual decline in both the number of PLHIV and AIDS-related mortality over the 12-year period, reflecting the positive impact of sustained national interventions, improved access to antiretroviral therapy, and targeted prevention efforts among high-risk populations. Despite this overall reduction, the persistently high burden of PLHIV highlights that the epidemic remains a major public health challenge.

The predictive equations generated in this study provide short-term forecasts that can serve as a useful quantitative tool for policymakers, programme planners and healthcare administrators. Forecasting PLHIV and HIV-related deaths offers valuable insight into the scale of future intervention needs, including treatment resources, testing capacity and healthcare infrastructure. The use of a quadratic trend, supported by the principle of least squares, proved effective for capturing the non-linear evolutionary pattern of HIV in India during this period.

While this study contributes to the literature by introducing a time-series forecasting model that simultaneously examines disease prevalence and mortality, there is scope for methodological enhancement. Future research could extend this modelling framework by incorporating more complex approaches such as ARIMA, exponential, logarithmic or machine-learning-based forecasting models, and by integrating behavioural, socioeconomic and demographic predictors. Expanding the analysis beyond national-level data to include state-level variations may also reveal spatial disparities critical for targeted interventions.

Overall, the findings reinforce that continued surveillance, strengthened health policies, and sustained investment in treatment and prevention remain essential to further reduce HIV-related morbidity and mortality in India. The predictive evidence generated in this study can support informed decision-making and contribute to the country's progress toward achieving the goal of ending AIDS as a public health threat. In future, we will explore this area by using more complex trend such as Exponential trend, Logarithmic trend, Lognormal trend etc.

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