Preplanned Studies

Economic Evaluation of the Comprehensive AIDS Prevention and Control Program — Tianjin Municipality, China, 2011–2022

Maohe Yu[1,2,&]; Jianping Wang[3,4,&]; Jinhua Zhao[3,4]; Yan Guo[1]; Jianyun Bai[1]; Zhongquan Liu[1]; Hui Gong[1]; Tielin Ning[1]; Minna Zheng[1]; Jinyu Hou[1]; Zhuang Cui[3,4,#]

Summary

What is already known about this topic?

Acquired immunodeficiency syndrome (AIDS) represents a significant public health challenge globally, not only inflicting harm on the health of individuals but also placing a considerable economic strain on society.

What is added by this report?

This study represents the inaugural report on the potential reduction in economic burden attributable to human immunodeficiency virus (HIV) prevention strategies in Tianjin. Between 2011 and 2022, it is estimated that effective measures could prevent 2,965 new HIV infections and avert 658 deaths, resulting in an economic benefit of approximately 14.437 billion Chinese Yuan.

What are the implications for public health practice?

The findings of this study offer valuable evidence to inform the development of localized HIV prevention and control strategies, as well as to guide public health policymaking.

Human immunodeficiency virus (HIV) infection and the resulting acquired immunodeficiency syndrome (AIDS) pose a significant global health crisis (*1*). The associated economic burden is substantial (*2*–*3*). In this study, using a Susceptible-Infected-Recovered-Deceased (SIRD) model and incorporating HIV epidemic surveillance data from Tianjin Municipality, China, we estimated the cumulative number of infections and deaths prevented, annual new infections, deaths, and the socioeconomic impact of HIV preventative and control measures in Tianjin from 2011 to 2022. The findings indicate that between 2011 and 2022, HIV prevention efforts may have averted a total of 2,965 infections and 658 deaths, leading to an economic benefit of approximately 14.437 billion Chinese Yuan (CNY). These outcomes underscore that effective prevention and control strategies have the potential to mitigate the spread of AIDS and lessen its economic impact.

The SIRD model was employed to segment the population into four distinct categories — susceptible (S), infected (I), recovered (R), and dead (D). This model was utilized to project the number of infections and deaths that would theoretically occur without the implementation of innovative and precise AIDS prevention and control measures. The simulations were based on transmission coefficients and mortality rates from 2010, which served as the baseline scenario. Following this, the actual outcomes were compared against the projections to estimate the annual number of new infections and deaths, as well as the aggregate reduction of infections and deaths, in Tianjin over the period from 2011 to 2022. Herein, 'S' represents the portion of the population who are healthy but lack immunity, while 'I' denotes individuals infected with HIV.

The model operates under the assumption that the transmission, recovery, and mortality rates remain constant over time. The system is described by the following set of differential equations.

$$\begin{aligned} dS/dt &= -\lambda \times S \times I/N \\ dI/dt &= \lambda \times S \times I/N - \mu \times I - \delta \times I \\ dR/dt &= \mu \times I \\ dD/dt &= \delta \times I \end{aligned} \tag{1}$$

Where N=8,730,300, is the total population aged 15 years and above in Tianjin in 2010, from the statistical yearbook. λ is the transmission coefficient, which is 0.25 (*4*). The recovery coefficient μ is 1–10, which we set to a very small value due to the fact that AIDS is almost incurable. δ is the mortality rate, which is 0.02 (*5*–*6*). Obtaining the baseline of AIDS in 2010 from the Networked Direct Reporting of Infectious Diseases (NDRID) system, where I(0)=786, R(0)=0, D(0)=2. The model assumes N=S+I+R+D.

Based on cost analyses conducted by real-world data measurements from designated medical institutions and the literature (*7–8*), the average annual outpatient expense for treating an AIDS patient is approximately 3,400 CNY in the initial year, with subsequent annual costs averaging around 1,600 CNY. Furthermore, patients receive two complimentary CD4 tests annually at a cost of 360 CNY, a viral load test provided without charge for 1,300 CNY, and free antiretroviral therapy drugs estimated to cost about 1,679 CNY per patient per year. When hospitalization is required for the treatment of opportunistic infections, the cost averages 25,570.5 CNY per admission. Prior research and evaluations by the designated medical institutions suggest that the average treatment duration needed for an AIDS patient in Tianjin spans approximately 15 years (*9*).

The formula for calculating the cost of state financial support and the cost of health insurance, individual outpatient treatment, and treatment of opportunistic infections saved by the prevention of new infections are as follows (*10*).

$$E_{i1} = N_i \times 15\ years \times (2 \times CD4\ test + viral\ load\ test + antiretroviral\ therapy\ drugs) \quad (2)$$

$$E_{i2} = N_i \times (first\ year\ outpatient\ cost + 14\ years \times follow\ up\ outpatient\ cost + average\ hospitalization\ cost) \quad (3)$$

N_i was the cumulative prevention of infections.

The per capita GDP of Tianjin in 2011–2022 was 61,458.41 CNY, 66,517.25 CNY, 71,344.62 CNY, 74,960.34 CNY, 75,868.27 CNY, 79,647.47 CNY, 87,280.48 CNY, 95,688.65 CNY, 101,556.79 CNY, 101,614.21 CNY, 113,190.83 CNY, and 118,800.00 CNY. Concurrently, an analysis of the disability-adjusted life years (DALYs) per prevention in HIV infections was 31.05, 29.29, 30.78, 36.37, 41.80, 45.48, 46.76, 46.86, and 46.19 for 2011–2019 (*11*), and the 2020, 2021, and 2022 years using DALY 2019. The methodology utilized to calculate the economic benefits resulting from the reduction in new HIV infections E_{i3} is as follows (*12*).

$$E_{i3} = \sum_{t=2011}^{2022} \left(DALYs_t \times N_t \times (per\ capita\ GDP)_t\right) \quad (4)$$

t denotes the year. $DALYs_t$, N_t, $(per\ capita\ GDP)_t$ were the DALYs, reduced infections, and per capita GDP in year *t,* respectively.

Patients with AIDS and their families annually incur costs of 240.6 CNY for transportation, 88.44 CNY for accommodation, and 460.2 CNY for nutrition, respectively (*13*). The formula to calculate additional cost savings achieved by preventing new infections is provided in reference (*10*).

$$E_{i4} = N_i \times 15\ years \times (transportation\ cost + accommodation\ cost + nutrition\ cost) \quad (5)$$

The total economic benefit of reducing infections (E_i) is calculated as follows.

$$E_i = E_{i1} + E_{i2} + E_{i3} + E_{i4} \quad (6)$$

Between 2011 and 2022, the life expectancy of AIDS patients increased by an average of 12 years. The Health State Utility (HSU) for AIDS patients undergoing antiretroviral therapy is valued at 0.82 (*12*). The average per capita GDP in Tianjin during this timeframe was 87,327.28 CNY. To calculate the economic benefits derived from the prevented deaths, subtract the cost of treatment and additional expenses incurred during the extended survival period, including transportation, accommodation, and nutritional costs, according to the formula presented in reference (*10*).

$$E_{d1} = N_d \times average\ per\ capita\ GDP \times 12\ years \times DALY \quad (7)$$

$$E_{d2} = N_d \times 12\ years \times (Follow-up\ outpatient\ cost + 2 \times CD4\ test + viral\ load\ test + antiretroviral\ therapy\ drugs) \quad (8)$$

$$E_{d3} = N_d \times 12\ years \times (transportation\ cost + accommodation\ cost + nutrition\ cost) \quad (9)$$

N_d was the cumulative effect on the prevention of deaths.

The total economic benefit of reducing deaths (E_d) is calculated as follows.

$$E_d = E_{d1} - E_{d2} - E_{d3} \quad (10)$$

Considering the extended duration of the study, we conducted additional analysis on the economic advantages, applying an annual discount rate of 5% (*14*). All statistical analyses were conducted utilizing the Policy and Numpy packages in Python (version 3.8), complemented by the use of Microsoft Excel (version 2016, Microsoft Corporation, USA).

As shown in Figure 1, there is no significant difference in the number of infections per year during 2011–2013 compared to the actual situation. Infections prevented each year from 2014–2022 were 81, 147, 228, 337, 383, 442, 510, 213, and 612, respectively, with a total of 2,965 cases prevented from 2011–2022. Deaths prevented annually during the AIDS prevention and treatment program were 17, 22, 15, 11, 22, 34, 58, 68, 59, 87, 107, and 158, respectively, resulting in a cumulative prevention of 658 deaths over 12 years.

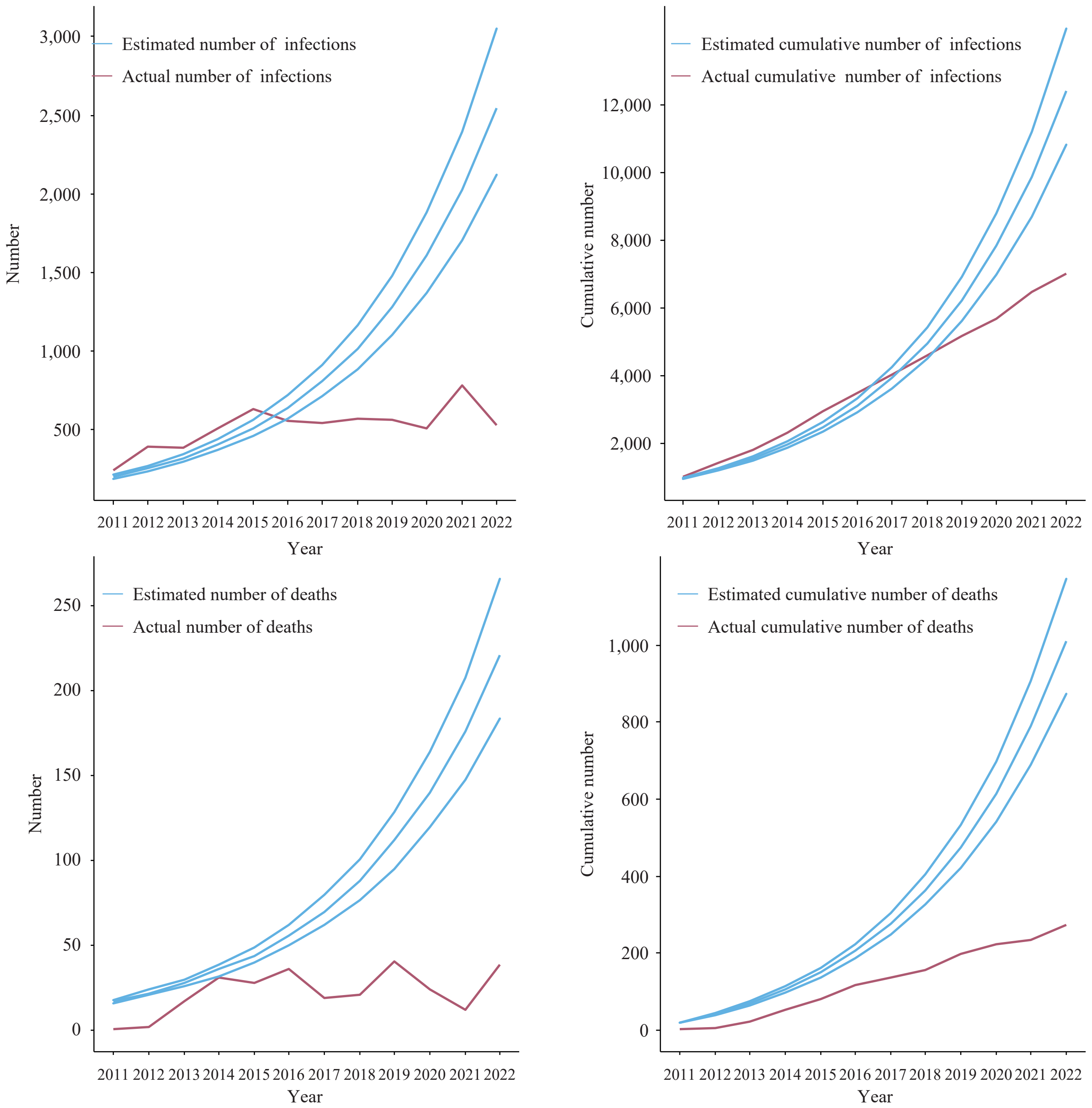

FIGURE 1. Annual prevention of infections and deaths and cumulative prevention of infections and deaths in Tianjin, 2011–2022.

As shown in Table 1, the economic benefits of prevented infections and deaths are valued at 13.920 billion CNY and 0.523 billion CNY, respectively.

DISCUSSION

Between 2011 and 2022, Tianjin's comprehensive HIV/AIDS prevention and control initiative has yielded significant outcomes. The program has averted 2,965 new infections, yielding an economic benefit of 13.920 billion CNY, and has prevented 658 deaths, which translates to an economic benefit of 0.517 billion CNY. The total economic benefit amounts to 14.443 billion CNY. These figures highlight that HIV/AIDS imposes a substantial economic burden, affecting both individuals and society. Other research corroborates the heavy disease burden attributed to AIDS (*13*). Consequently, maintaining and enhancing prevention and control efforts to stem HIV infection and mortality rates continues to be a priority for

TABLE 1. Economic benefits of HIV prevention measures in preventing infections and deaths with and without discounting in Tianjin Municipality, China, 2011–2022.

Sources of economic benefits	Economic benefits (billion CNY)	Discounting (billion CNY)
Infections		
E_{i1}	0.165	0.174
E_{i2}	0.152	0.160
E_{i3}	13.568	14.282
E_{i4}	0.035	0.037
Total	13.920	14.653
Deaths		
E_{d1}	0.565	0.595
E_{d2}	0.042	0.044
E_{d3}	0.006	0.006
Total	0.517	0.545

Abbreviation: HIV=human immunodeficiency virus; CNY=Chinese Yuan.

Tianjin.

The modeling of infectious disease dynamics relies on understanding the survival characteristics of a population, the incidence of diseases, and the laws governing the spread of infections. To quantitatively analyze the progression of infectious diseases and predict future trends, mathematical models are established and subjected to numerical simulation. This modeling provides a crucial quantitative foundation for sounding alarms in public health prevention and control efforts. Among the various models utilized, the susceptible-infected-recovered base model (SIR model) stands as the foundational and most significant approach in today's modeling landscape. Regarding the study area, the SIR model assumes that the total population remains constant, not accounting for changes due to births, deaths, mobility, and other factors. Nonetheless, when examining HIV/AIDS infection dynamics, the number of deaths attributable to AIDS and the number of individuals successfully treated are of profound public health importance. Consequently, we cannot simply group those exiting the system into a single category. Given that we have data on both the number of successful treatments (cures) and the number of deaths, we adapt our approach according to the specific characteristics of HIV/AIDS infections. In this paper, we employ a generalized form of the SIR model known as the SIRD model. The SIRD model presents certain advantages over traditional assessment methods in the domain of AI defense. First, SIRD is capable of modeling and forecasting the dynamic shifts in infectious diseases based on their transmission traits and influencing factors, something that classical assessment methods in AI defense struggle to undertake in terms of quantitative analysis and prediction. Second, SIRD assists policymakers in assessing the efficacy of various interventions on epidemic spread — a dimension that AI defense methods tend to overlook, focusing instead on system safety and robustness. Third, SIRD can integrate actual data for parameter estimation and model calibration, enhancing model accuracy and reliability. This stands in contrast to the AI defense field, where classical assessment methodologies tend to rely more heavily on simulation and emulation, making less use of empirical data (*15–17*).

Over the past ten years, the epidemiological landscape of HIV has undergone a significant shift. Sexual transmission has now become the predominant mode of infection, with men who have sex with men (MSM) facing a risk of HIV infection that is 22 times higher than that of the general population. This demographic has emerged as the fastest-growing segment among new HIV diagnoses in China (*18*). In response to these dynamics, Tianjin has adopted a pioneering approach labeled "innovative model, precise prevention and control" for AIDS management. This initiative has led to the establishment of China's inaugural pilot program for HIV intervention tailored to MSM in bathhouses and the creation of voluntary counseling and testing clinics with city-wide coverage. Additionally, Tianjin has implemented two phases of comprehensive HIV prevention and treatment demonstration areas and intensified efforts in nucleic acid monitoring and transmission testing among MSM. A cornerstone of infection source control is the policy of immediate treatment upon HIV detection. Since 2011, Tianjin has enforced free HIV testing in outpatient units of critical hospital departments, advancing early identification and management efforts. Collectively, these strategies have successfully maintained a low prevalence of AIDS within the Tianjin population.

Utilizing the aforementioned methodology enables the quantification of the economic burden alleviated within a specific region over a defined timeframe due to proactive HIV/AIDS prevention and treatment initiatives. This data serves as an integral reference point and foundation for judiciously assessing investments in HIV/AIDS prevention and treatment, optimizing resource distribution, and refining policies and strategies. Such adjustments are essential for the effective realization of HIV/AIDS prevention and treatment objectives.

While the assessment of the economic benefits has accounted for numerous factors, it does not fully account for certain costs, including the treatment and care associated with opportunistic HIV infections and the prevention of mother-to-child transmission. This omission could lead to an underestimation of the economic benefits derived from preventive measures. Furthermore, the model does not reflect age-specific differences, thereby limiting the ability to ascertain the impact of preventive strategies on various population segments, which may compromise the accuracy of the estimated economic benefits. Additionally, due to limitations in the available data, this study provides point estimates without corresponding interval estimates. Although point estimates are unable to convey the possible range of outcomes, they offer valuable insight into the general trends and critical aspects of the issue at hand. Another limitation is the lack of precise data on total population figures or demographic shifts. Consequently, this study does not thoroughly examine the potential implications such changes may have on the model's accuracy and applicability. Future research will aim to enhance model precision by incorporating comprehensive data on population dynamics.

In conclusion, the HIV prevention and control strategies presently implemented in Tianjin have not only successfully curbed the incidence of HIV infections and associated mortality but have also yielded significant economic advantages. Maintaining and reinforcing these existing measures will continue to be of paramount importance for Tianjin in the ensuing years.

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Corresponding author: Zhuang Cui, cuizhuang@tmu.edu.cn.

[1] STD & AIDS Control and Prevention Section, Tianjin Centers for Disease Control and Prevention, Tianjin, China; [2] Tianjin Key Laboratory of Pathogenic Microbiology of Infectious Disease, Tianjin Centers for Disease Control and Prevention, Tianjin, China; [3] Department of Epidemiology and Biostatistics, School of Public Health, Tianjin Medical University, Tianjin, China; [4] Tianjin Key Laboratory of Environment, Nutrition and Public Health, Tianjin, China.
[&] Joint first authors.

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