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Estimation of burden of cancer incidence and mortality in India: based on global burden of disease study 1990–2021

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Abstract

Background Cancer poses a significant public health challenge in India, making it crucial to predict its future impact for effective healthcare planning. This study forecast cancer incidence, mortality, and disability-adjusted life years (DALYs) in India from 2022 to 2031.

Methods We extracted age-standardized data on incidence, prevalence, DALYs, and mortality from 1990 to 2021 from the Global Burden of Disease (GBD) study. We used Decadal Average Percentage Change techniques to identify trends in cancer burden over decades and the Autoregressive Integrated Moving Average (ARIMA) method were used for forecasting. The ARIMA (2,2,2) model was identified as the best for predicting cancer incidence, ARIMA (0,3,3) for DALYs, and ARIMA (0,2,2) for mortality.

Results The cancer incidence rate is expected to rise from 529.40 (95% CI: 525.41-533.38) in 2022 to 549.17 (95% CI: 487.43-610.92) per 100,000 population in 2031. The DALYs rate is projected to decrease from 2001.53 (95% CI: 1964.24-2038.82) in 2022 to 1842.08 (95% CI: 1273.57-2410.60) per 100,000 population in 2031, indicating improvements in cancer burden management. Mortality rates are forecasted to increase slightly, from 71.52 (95% CI: 69.91–73.12) in 2022 to 73.00 (95% CI: 60.88–85.11) per 100,000 population in 2031. Overall, while incidence and mortality rates show a slight upward trend, the DALYs rate is projected to decrease, reflecting potential advancements in cancer management and treatment over the forecast period.

Conclusions Over the next decade, cancer incidence and mortality are expected to increase in India, highlighting the need for enhanced prevention, early detection, and proper treatment strategies. Despite these increases, the anticipated decrease in DALYs suggests potential advancements in cancer management, warranting further investigation into the drivers of this positive trend and measures to sustain it.

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Keywords Cancer, Incidence, Disability-adjusted life years, Mortality, Forecast, Global burden of disease

Introduction

Cancer continues to be a leading cause of morbidity and mortality worldwide. Cancer presents a significant global health challenge with a projected surge in cases. In 2022, nearly 20 million people were detected 10 million succumbed to the diseas. This burden is expected to worsen, with estimates suggesting a 77% increase in new cases by 2050. Lung cancer currently reigns as the most common andmost frequently diagnosed cancer, followed by breast and colorectal cancers. These sobering statistics emphasize the urgent need for effective prevention, diagnosis, and treatment strategies to combat this growing global threat [1]. Recent years have seen significant changes in the global burden of cancer (GBD), with variations in incidence, mortality, and disability-adjusted life years (DALYs) across different regions and cancer types. A new GBD report 2021 reveals a worrying rise in global cancer burden, with incidence rates jumping 29% from 651.98 per 100,000 in 1990 to 842.43 in 2021, while mortality rates increased by 16% from 108.45 per 100,000 in 1990 to 125.31in 2021 [2].

Cancer, a formidable foe in the global health arena, casts a long shadow across nations. Millions are diagnosed annually, straining healthcare systems and societies. South Asia, a region experiencing rapid demographic shifts and lifestyle changes, faces a particularly concerning rise in cancer cases [3]. India, the most populous nation, this translates to a harsh reality – a growing cancer burden with projected increases in both incidence and mortality rates. This rise in India can be attributed to several factors such as rapid urbanization, an aging population, increasingly sedentary lifestyles, and unhealthy dietary choices. Additionally, exposure to both indoor and outdoor air pollution is a growing concern [4]. Population aging plays a significant role, as the risk of cancer increases with age [5]. Alcohol and smoking are the leading risk factors for laryngeal cancer (LC), with global trends indicating a decrease in age-standardized mortality rates but an increase in the absolute number of deaths, emphasizing the critical need for effective smoking control and alcohol consumption reduction strategies [6]. Additionally, changing lifestyles, including increased tobacco use, unhealthy diets, and lack of physical activity, contribute to the problem. However, a crucial caveat emerges – an estimated 80% of these projected cases are believed to be preventable. By focusing on modifiable risk factors like tobacco use, lifestyle changes and certain infections, India can potentially mitigate a significant portion of this future burden. This emphasizes the critical role of preventive strategies. Public health initiatives promoting healthy lifestyles, tobacco control measures, and vaccinations against cancer-causing viruses are crucial steps in combating this growing challenge [7].

Prior research has explored the national picture of cancer burden and its variations across India. These studies have also identified key areas for improving cancer control efforts in the country [8–10]. GBD data paints a concerning picture, with millions succumbing to this disease annually. The mortality rate in 1990 was 41.39 per 100,000 population and 60.44 per 100,000 in 2021. This represents a 46.02% increase in three decades. The incidence rate and DALYs rate of cancer increased by 34.94% and 22.48% between 1990 and 2021 respectively. A previous study reported a substantial increase in cancer burden in India between 1990 and 2021, emphasizing the importance of preventive and early detection strategies [11]. A significant shift has occurred in the leading cause of cancer death in India, according to the 2021 GBD report. Breast cancer has overtaken stomach cancer, which held the top spot in 1990. This highlights the changing landscape of cancer burden in the country. In India, breast cancer stands out as the most frequent cause of both new cancer diagnoses and cancer deaths among women. It was responsible for over 13.5% of all new female cancers and 10% of cancer deaths in women in 2020 [12].

This overwhelming burden has resulted in characterizations of India's cancer situation as an epidemic or a tsunami [13–15]. Fighting cancer is a global priority, with the United Nation Sustainable Development Goal (SDG) aiming to reduce cancer deaths by a third by 2030. Data from the National Cancer Registry Programme (NCRP) paints a worrying picture, projecting a significant increase in total cancer cases in India. From nearly 1 million in 2010, the number is projected to surpass 1.1 million by 2020. India initiated its NCRP in 1982. Since then, the program has steadily grown, incorporating population-based cancer registries (PBCRs) in various urban centres and expanding to include some rural areas. Effective cancer control in India requires a multipronged approach that includes enhancing healthcare infrastructure, promoting education and awareness about cancer prevention, and implementing state-specific cancer control programs [16].

Extensive research has been carried out to measure the scope of the cancer problem in India [8, 16–19]. The GBD study's metrics offer a comprehensive overview of cancer's impact, facilitating a better understanding of its future trajectory and aiding in the formulation of targeted interventions. A confluence of factors is driving the rise in cancer cases worldwide, particularly in middle- and low-income countries like India. Thus, understanding the current landscape through the GBD study's metrics is crucial for policymakers, healthcare providers, and researchers to develop effective strategies aimed at mitigating the future impact of cancer in India. The use of statistical modelling approaches such as the Autoregressive Integrated Moving Average (ARIMA) models has become increasingly prevalent in epidemiological studies for forecasting disease trends. ARIMA models are particularly useful due to their ability to handle time series data with trends and seasonality, making them ideal for predicting cancer incidence and mortality rates. These models help in understanding the past and current trends and provide projections that can guide policymaking and resource allocation in the healthcare sector [20]. Extensive utilization of ARIMA models in cancer studies, including breast cancer and oral cancer, underscores their effectiveness in capturing the complexities of disease progression, making them ideal for projecting future cancer incidence and mortality rates [21, 22].In the context of cancer forecasting, ARIMA models have been employed to predict future trends based on historical data. This approach considers the autoregressive nature of cancer incidence and mortality, integrates the differences in the data to stabilize the mean, and uses moving averages to smooth out short-term fluctuations [21, 23].

This study delves into the multifaceted challenge of cancer in India by analysing trends, decadal changes, gender disparities, and spatial variations. By incorporating future predictions for cancer incidence, DALYs and mortality, we aim to provide a nuanced understanding of this public health concern. This knowledge will be instrumental in informing targeted interventions and resource allocation strategies to not only mitigate the rising cancer burden but also improve health outcomes across the nation. Therefore, leveraging advanced modelling techniques to project cancer trends is a vital component of public health planning in India.

Methods

Data sources

This study utilized age-standardized data on cancer incidence, prevalence, DALYs, and mortality for India from the GBD study for the period 1990 to 2021 (https://vizhub.healthdata.org/gbd-results/) [2]. This analysis utilizes cancer data estimates provided by the Institute for Health Metrics and Evaluation (IHME) in collaboration with the Indian Council of Medical Research (ICMR) and the Public Health Foundation of India (PHFI). High-quality data on cancer incidence and survival are collected by Population-Based Cancer Registries (PBCRs), which cover various geographic regions and time periods. Hospital discharge records provide information on cancer diagnosis, treatment, and outcomes, particularly in countries with extensive healthcare systems and electronic health records. Autopsy reports contribute data on cause of death, particularly in regions where other data sources may be limited. Through a systematic and transparent statistical modelling process, the GBD study generates estimates that account for variations in data quality and availability across different locations. This modelling process involves the use of advanced statistical techniques to integrate and harmonize data from disparate sources, ensuring robust and comparable estimates of cancer burden.

The data and estimates generated by the GBD study are essential for understanding the burden of cancer in India and for informing public health policies and cancer control strategies. By leveraging the comprehensive data and methodological rigor of the GBD study, this research provides a detailed and accurate assessment of cancer trends in India over the past three decades.

Statistical analysis

To elucidate the evolving landscape of cancer burden in India, this study adopted a two-pronged analytical approach utilizing R software (version 4.0.1). First, we investigated historical trends (decadal) in cancer incidence, prevalence, DALYs and mortality across various demographics. This analysis provided insights into the past patterns of cancer burden within different population subgroups. Second, we leveraged time series models to forecast these indicators for the next decade. This approach aligns with the widely used time series forecasting methodology, which meticulously analyses past observations to construct a model that captures the underlying structure of the data. Similar to how the ARIMA model is a popular choice for stochastic time series analysis, this study utilizes time series models to predict the future trajectory of cancer burden in India. This forecasting component allows us to anticipate potential changes in cancer burden and inform future resource allocation, preventative measures, and healthcare infrastructure development.

The ARIMA model emerges as a powerful tool for analyzing cancer burden data due to its ability to capture various aspects of time series. Unlike simpler models, ARIMA accounts for changing trends, seasonal fluctuations, and random variations within the data. This makes it suitable for forecasting cancer incidence, prevalence, and mortality, which can exhibit complex patterns over time [23]. This initial stage involves exploring different ARIMA configurations (p, d, q) based on statistical tests and visual inspection of data characteristics The ARIMA model, denoted as ARIMA (p, d, q), captures the influence of past observations (p), removes trends through differencing (d), and accounts for random errors with a moving average term (q). These parameters (p, d, q) are determined by analyzing the data's autocorrelation and partial autocorrelation patterns to identify significant lags. The model is then fine-tuned by estimating the optimal values for p, d, and q. Finally, the model's adequacy is ensured by verifying its residuals resemble random noise, a characteristic of a good fit. Once this rigorous process is complete, the chosen ARIMA model with its estimated parameters can be used to forecast future cancer burden trends.

The ARIMA model itself is a combination of two submodels: the Autoregressive (AR) model and the Moving Average (MA) model. The integration step (denoted by d) removes non-stationarity, a common challenge in time series data. This allows for more accurate forecasting. While the specifics of AR and MA models involve mathematical formulas, the key takeaway is that ARIMA effectively captures trends and variations within cancer burden data, enabling researchers to predict its future trajectory. The general formula of AR (*p*) and MA *(q)* models can be expressed in Eqs. (1) and (2), respectively.

An autoregressive AR(p) model of order p can be written as:

$$y_t = c + \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + \dots + \varphi_p y_{t-p} + e_t \tag{1}$$

Where c is a constant, e_t is a white noise $e_t \sim N(0, \sigma^2)$, $\varphi = (\varphi_1,\ \varphi_2, \dots, \varphi_p)$ is the vector of model coefficients & *p* is a non-negative integer.

A moving average MA(q) model of order q uses past forecast errors in a regression model as:

$$y_t = c + e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} - \dots - \theta_q e_{t-q} \tag{2}$$

Where c is a constant, e_t is a white noise $e_t \sim N(0, \sigma^2)$,, $\varphi = (\theta_1,\ \theta_2, \dots, \theta_q)$ is the vector of model coefficients & *p* is a non-negative integer.

ARIMA (p, q) model can be written as:

$$y_t = c + \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + \dots + \varphi_p y_{t-p} + e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} - \dots - \theta_q e_{t-q}$$

$$y_t = c + \sum_{i=1}^{p} \varphi_i y_{t-i} - \sum_{j=1}^{q} \theta_j e_{t-j} + e_t \tag{3}$$

ARIMA (p, d, q) model can be written as:

$$y_t - 2y_{t-1} - \dots - y_{t-d} = c + \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + \dots + \varphi_p y_{t-p} + e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} - \dots - \theta_q e_{t-q} \tag{4}$$

Where, p autoregressive terms, d is the non-seasonal differences, q is the number of lagged forecast errors.

To identify the most optimal model for forecasting, we employ two key criteria: Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The model with the lowest AIC and BIC values is considered the most suitable for predicting future trends in cancer burden data.

$$AIC = 2 \times k - 2 \times \log(L) \tag{5}$$

$$BIC = k \times \log(n) - 2 \times \log(L) \tag{6}$$

Where $k (= p + q + 1)$ is the number of parameters in the statistical model and L is the maximizes value of the likelihood function for the estimated model.

To ensure the data's suitability for time series analysis of cancer burden, we conducted the Dickey-Fuller test for stationarity. This test revealed that stationarity was achieved only after differencing the data a specific number of times (indicated by the differencing order). Subsequently, we proceeded with ARIMA model application. To evaluate the model's forecasting accuracy, we employed established metrics like Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE).

Results

To understand the historical trends in cancer burden, we first present data from the GBD study for the period 1990–2021.

Based on the data in the Table 1 it is possible to draw some conclusions about changes in deaths and DALYs in India between two decades from 1990 to 2021. The table stratifies the data by gender, age groups, and specific risk factors. Females generally fared better than males in terms of deaths and DALYs. From 1990 to 2000, deaths for females decreased slightly (-0.06%) and DALYs also decreased (-0.07%). In contrast, males males saw no change in deaths (0.00%) but a small decrease in DALYs (-0.01%). The data suggests an association between age and mortality rates. The youngest age group (0–14 years) showed a significant decrease in both deaths and DALYs (-0.27%) from 2000 to 2010. Similarly, the50–74 age group experienced a decline in both deaths and DALYs (-0.06%) during this decade. However, the trend reversed for the elderly population (75+years) who witnessed an increase in deaths (0.16%) and DALYs (0.17%). In the decade from 2010 to 2021, the 85+age group experienced an increase in deaths by 0.21% and in DALYs by 0.22%. The analysis of specific risk factors like tobacco use displayed a decrease in deaths (-0.02%) and DALYs (-0.04%) suggesting potential improvements in tobacco control efforts in the decade 2010 to 2021. Conversely, metabolic risks emerged as a growing concern, with an increase in deaths (0.39%) and DALYs (0.38%). Other environmental risks remained relatively constant, with a minimal increase in deaths (0.02%) 2000 to 2010, followed by an increase of 0.15% from 2010 to 2021 and a slight rise in

Table 1 Distribution of cancer cases by risk factors and average decadal trend

Variables	Year											
	1990–2000				2000–2010				2010–2021			
	Deaths	% changes	DALYs	% changes	Deaths	% changes	DALYs	% changes	Deaths	% changes	DALYs	% changes
ASDR	70.21	-0.03	2105.68	-0.04	66.20	-0.03	1933.88	-0.06	70.52	0.08	2001.27	0.05
Gender												
Male	74.42	0.00	2125.75	-0.01	72.75	0.01	2030.44	-0.02	76.59	0.06	2064.03	0.02
Female	66.32	-0.06	2096.29	-0.07	60.33	-0.06	1849.73	-0.10	65.60	0.11	1955.70	0.09
Age groups												
0–14	5.26	-0.08	442.83	-0.09	4.14	-0.27	347.50	-0.27	3.39	-0.23	284.06	-0.23
15–49	20.39	-0.02	1066.48	-0.01	19.18	-0.07	1005.44	-0.07	19.45	0.03	1005.35	0.02
50–74	220.17	-0.01	6430.40	-0.04	203.90	-0.06	5840.90	-0.06	215.48	0.09	6220.40	0.09
75–84	417.32	0.03	6298.20	0.04	426.83	0.06	6424.64	0.05	471.54	0.11	7009.84	0.11
85+	518.88	0.00	5063.26	-0.02	550.46	0.16	5336.18	0.17	688.25	0.21	6696.01	0.22
Risk Factors												
Tobacco	12.80	-0.08	340.98	-0.09	11.52	-0.07	301.60	-0.08	11.16	-0.02	287.02	-0.04
Air Pollution	2.10	-0.02	56.27	-0.02	1.96	-0.06	52.05	-0.07	2.04	0.08	53.91	0.06
Dietary risks	4.05	-0.04	110.49	-0.03	3.82	-0.03	102.50	-0.06	3.96	0.06	104.99	0.04
Environmental/ Occupational risks	2.77	0.00	75.13	0.00	2.65	-0.03	71.36	-0.04	2.84	0.10	75.54	0.08
Metabolic risks	1.46	0.24	36.78	0.26	1.75	0.23	43.86	0.21	2.35	0.39	58.45	0.38
Occupational risks	0.71	0.06	20.26	0.06	0.73	0.06	20.68	0.05	0.83	0.15	22.69	0.11
Other environmental risks	0.24	0.02	6.35	0.02	0.23	0.02	6.22	0.01	0.26	0.15	6.92	0.13

DALYs from 0.01% to (0.02%) over the decade from 2010 to 2021.

Overall, the data highlights subtle changes in deaths and DALYs across different demographics and risk factors over two decades between 1990 and 2021. From 2010 to 2021, a positive trend was observed in the reduction of both deaths and DALYs among younger age groups and individuals impacted by tobacco use. However, the data also suggest s a need to address the growing concern of metabolic risks and the increasing burden of deaths and DALYs among the elderly population.

Table 2 highlights the percentage changes in prevalence and incidence rates across different states and union territories (UTs) in India over three decades: 1992–2001, 2002–2011, and 2012–2021. From the first to the last two decades, Arunachal Pradesh's cancer prevalence rates increased by 10.77% and 20.05%, while Bihar saw rises of 7.73% and 19.04%. Delhi and Kerala experienced significant increases, with Delhi's prevalence growing by 19.62% and 28.17%, and Kerala's by 21.57% and 31.89%. Other notable increases include Gujarat (16.02% and 25.47%), Maharashtra (13.56% and 26.13%), and West Bengal (15.43% and 26.33%). Overall, the data indicates a substantial rise in cancer prevalence across various Indian states over the past two decades. Kerala had the highest percentage change in prevalence rates at 31.89% in the last two decades, while Bihar had the lowest at 7.73% in the first two decades. Similarly, over the past two decades, cancer incidence rates have notably increased across Indian states. Kerala saw the highest rise at 14.30% and 19.58%, while Bihar experienced the lowest increase at 5.54% and 13.12%. Other significant increases include Delhi (13.89% and 19.07%), Gujarat (11.53% and 17.10%), and Maharashtra (9.72% and 17.40%). Overall, both

Table 2 Trends of cancer prevalence rates and incidence rate in different States/UTs of India over the last 3 decades

States/UTs	Average Decadal Prevalence Rate			Average Decadal Incidence Rate			% in Average Prevalence Rate		% change in Average Decadal Incidence Rate	
	1992–2001	2002–2011	2012–2021	1992–2001	2002–2011	2012–2021	First two Decades	Last two Decades	First two Decades	Last two Decades
Andhra Pradesh	737.86	855.59	1050.11	395.91	442.46	513.83	15.95	22.74	11.76	16.13
Arunachal Pradesh	752.68	833.74	1000.89	394.92	423.89	483.23	10.77	20.05	7.34	14.00
Assam	736.34	845.65	1004.44	393.54	437.14	497.88	14.85	18.78	11.08	13.89
Bihar	691.94	745.46	887.41	371.43	392	443.43	7.73	19.04	5.54	13.12
Chhattisgarh	748.18	849.24	1029.27	393.58	435.06	500.47	13.51	21.20	10.54	15.03
Delhi	776.62	928.97	1190.62	389.28	443.37	527.91	19.62	28.17	13.89	19.07
Goa	835.06	978.75	1224.07	421.39	473.98	556.64	17.21	25.06	12.48	17.44
Gujarat	715.72	830.38	1041.84	380.9	424.83	497.46	16.02	25.47	11.53	17.10
Haryana	718.71	836.04	1054.47	378.12	424.72	501.74	16.32	26.13	12.32	18.13
Himachal Pradesh	762.47	895.29	1102.11	402.81	456.19	534.9	17.42	23.10	13.25	17.25
Jammu & Kashmir and Ladakh	710.59	812.71	974.52	377.23	417	476.52	14.37	19.91	10.54	14.27
Jharkhand	704.72	788.37	949.84	376.67	408.25	463.16	11.87	20.48	8.38	13.45
Karnataka	999.62	1149.36	1381.56	463.63	514.99	590.92	14.98	20.20	11.08	14.74
Kerala	905.28	1100.51	1451.46	450.22	514.59	615.35	21.57	31.89	14.30	19.58
Madhya Pradesh	738.49	823.95	1014.69	388.11	420.39	488.73	11.57	23.15	8.32	16.26
Maharashtra	783.37	889.56	1122.04	401.75	440.82	517.51	13.56	26.13	9.72	17.40
Manipur	710.51	807.02	970.88	384.21	421.42	484.04	13.58	20.30	9.68	14.86
Meghalaya	692.87	777.51	936.64	379.61	412.09	473.19	12.22	20.47	8.56	14.83
Mizoram	791.68	914.17	1122.50	409.63	458.85	538.92	15.47	22.79	12.02	17.45
Nagaland	734.39	834.28	1021.50	383.73	421.93	493.66	13.60	22.44	9.95	17.00
Odisha	766.74	876.94	1069.25	404.79	449.29	521.23	14.37	21.93	10.99	16.01
Punjab	755.68	883.76	1096.67	392.83	441.54	516.55	16.95	24.09	12.40	16.99
Rajasthan	695.08	785.73	976.47	370.2	403.82	472.44	13.04	24.28	9.08	16.99
Sikkim	705.24	833.69	1044.11	375.04	426	505.55	18.21	25.24	13.59	18.67
Tamil Nadu	844.71	986.44	1211.66	430.11	479.12	553.56	16.78	22.83	11.39	15.54
Telangana	746.54	875.20	1093.43	392.56	441.1	516.81	17.23	24.93	12.36	17.16
Tripura	713.90	825.97	995.97	387.26	431.94	498.69	15.70	20.58	11.54	15.45
Uttar Pradesh	718.23	798.34	987.32	379.11	408.92	475.68	11.15	23.67	7.86	16.33
Uttarakhand	768.74	903.74	1121.11	401.85	455.52	531.89	17.56	24.05	13.36	16.77
West Bengal	774.01	893.40	1128.66	400.82	445.69	526.19	15.43	26.33	11.19	18.06
Other UTs	747.11	865.89	1079.55	389.46	434.37	512.3	15.90	24.68	11.53	17.94

prevalence and incidence rates have generally increased across the states and UTs over the three decades. The percentage changes indicate notable increases, particularly in the last two decades, suggesting a growing public health challenge.

Figure 1 illustrates the decadal changes in cancer burden (incidence, prevalence, DALYs, and mortality) across Indian states for both sexes from 1990 to 2021. The data reveals a moderate increase in cancer prevalence and incidence rates from 1990 to 2000, followed by a significant rise in incidence and DALYs from 2000 to 2010, with a slight decline in mortality. From 2010 to 2021, all parameters showed moderate increases, with a notable rise in mortality rates, suggesting an overall growing cancer burden over the last three decades. Specifically, for males, minimal increases were observed from 1990 to 2000, substantial rises in incidence and DALYs from 2000 to 2010, and a moderate increase in prevalence and DALYs from 2010 to 2021, with incidence rates stabilizing and mortality rates rising. For females, the first decade exhibited stable prevalence and minimal changes in other parameters, significant increases in incidence and DALYs from 2000 to 2010, and a moderate rise in all parameters from 2010 to 2021, with notable increases in DALYs and mortality rates. This overall trend indicates that while cancer incidence has risen significantly, the impact on DALYs and mortality has become more pronounced in recent years, reflecting a growing cancer burden in India.

Cancer prevalence in India exhibits marked disparities between genders and regions. As depicted in Fig. 2, males and females display distinct geographical patterns of cancer prevalence rate in 2021. The maps reveal regional disparities in cancer prevalence between genders. For males,

Table 3 Trends of cancer DALYs rates and mortality rate in different States/UTs of India over the last 3 decades

States/UTs	Average decadal DALY rate			Average decadal death rate			% change in average DALY rate		% change in average death rate	
	1992–2001	2002–2011	2012–2021	1992–2001	2002–2011	2012–2021	First two Decades	Last two Decades	First two Decades	Last two Decades
Andhra Pradesh	1277.75	1274.51	1403.87	36.32	39.73	48.63	-0.25	10.15	9.39	22.42
Arunachal Pradesh	2016.12	1865.02	1928.22	56.79	55.07	58.86	-7.49	3.39	-3.02	6.88
Assam	1896.74	1982.31	2016.12	52.80	57.78	62.11	4.51	1.71	9.43	7.51
Bihar	1398.36	1157.63	1173.77	37.05	32.89	37.35	-17.22	1.39	-11.21	13.55
Chhattisgarh	1675.49	1724.33	1950.10	47.13	50.53	60.29	2.92	13.09	7.21	19.32
Delhi	1680.89	1822.61	2008.90	44.68	52.19	63.37	8.43	10.22	16.82	21.41
Goa	1297.29	1394.61	1685.23	39.04	45.89	60.49	7.50	20.84	17.54	31.82
Gujarat	1107.35	1189.99	1542.96	30.94	35.77	48.38	7.46	29.66	15.60	35.24
Haryana	1398.65	1497.30	1784.22	40.81	45.65	57.66	7.05	19.16	11.84	26.33
Himachal Pradesh	1526.96	1578.39	1892.80	46.43	51.85	64.14	3.37	19.92	11.66	23.72
Jammu & Kashmir and Ladakh	1266.87	1267.56	1383.39	34.91	37.92	43.94	0.05	9.14	8.62	15.87
Jharkhand	1442.04	1326.15	1265.26	39.25	37.26	38.18	-8.04	-4.59	-5.07	2.46
Karnataka	1668.24	1656.17	1968.74	47.68	50.99	64.98	-0.72	18.87	6.95	27.42
Kerala	1883.28	2058.36	2393.12	62.13	71.83	95.44	9.30	16.26	15.63	32.86
Madhya Pradesh	1673.06	1585.25	1802.98	46.69	46.49	56.15	-5.25	13.74	-0.43	20.77
Maharashtra	1415.81	1331.60	1572.29	41.12	40.74	52.66	-5.95	18.08	-0.92	29.25
Manipur	1092.61	1117.63	1299.40	33.08	35.33	42.07	2.29	16.26	6.80	19.06
Meghalaya	1802.83	1796.83	2000.18	52.38	54.28	63.12	-0.33	11.32	3.63	16.29
Mizoram	2156.65	2352.15	2736.08	64.18	74.24	91.96	9.07	16.32	15.68	23.87
Nagaland	1737.70	1713.51	2033.12	49.17	51.91	64.90	-1.39	18.65	5.56	25.02
Odisha	1710.51	1777.21	1933.28	47.97	53.06	65.88	3.90	8.78	10.61	24.16
Punjab	1371.53	1389.93	1645.21	40.08	44.23	53.12	1.34	18.37	10.36	20.08
Rajasthan	1257.61	1211.46	1490.31	35.20	35.44	46.15	-3.67	23.02	0.70	30.22
Sikkim	1491.44	1607.84	1791.63	42.19	48.33	58.58	7.80	11.43	14.55	21.21
Tamil Nadu	1718.82	1764.01	1878.98	50.42	54.40	62.40	2.63	6.52	7.89	14.71
Telangana	1442.42	1492.58	1635.11	40.50	45.21	55.15	3.48	9.55	11.65	21.99
Tripura	1223.92	1280.11	1440.67	36.45	39.85	47.29	4.59	12.54	9.32	18.68
Uttar Pradesh	1624.77	1563.98	1798.28	44.41	45.34	57.24	-3.74	14.98	2.09	26.26
Uttarakhand	2011.35	2252.64	2585.08	56.94	67.38	81.65	12.00	14.76	18.33	21.19
West Bengal	1616.79	1547.74	1807.06	46.60	47.25	58.30	-4.27	16.75	1.39	23.38
Other UTs	1190.36	1242.94	1515.53	33.70	36.89	47.66	4.42	21.93	9.46	29.21

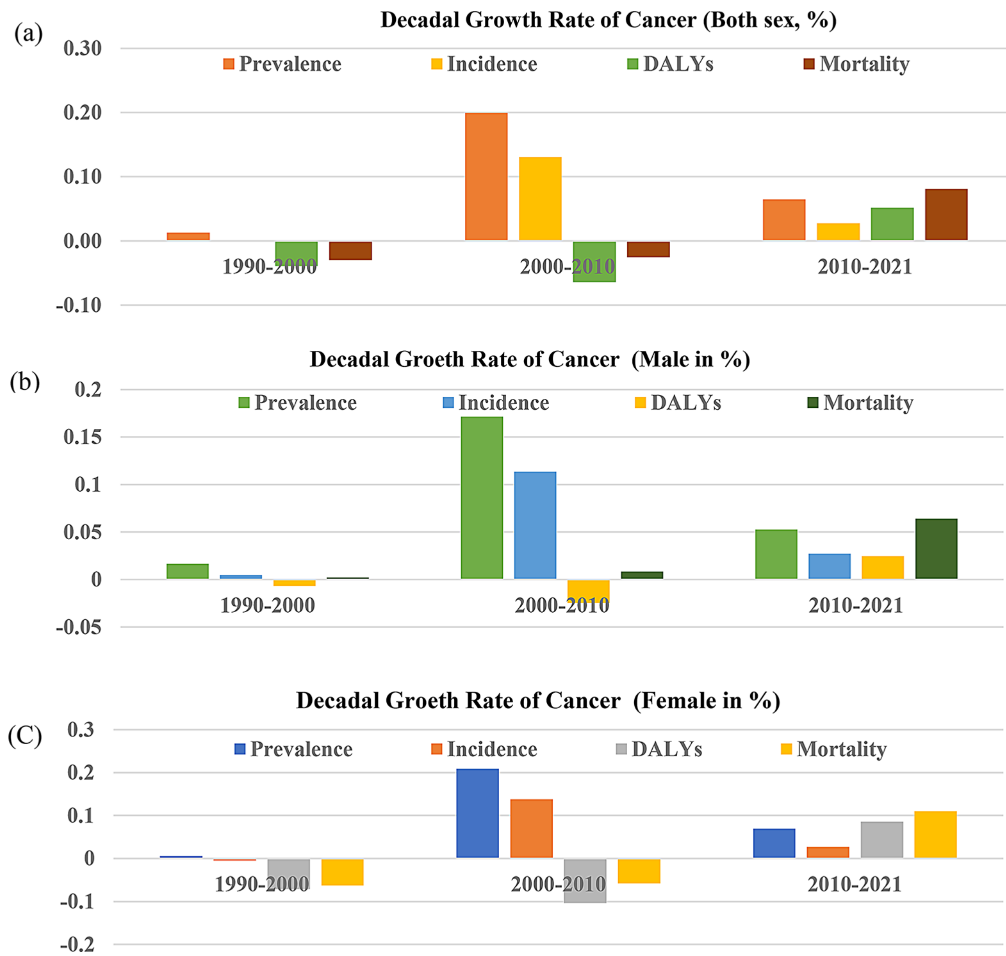

Fig. 1 Decadal changes in cancer burden incidence rate (incidence, prevalence, DALYs, and mortality) across Indian states (1990–2021) for both (**a**), male (**b**) and female (**c**)

the prevalence rates range from 651 to 908 per 100,000 population, with higher prevalence observed in states like Karnataka, Tamil Nadu, and West Bengal. Conversely, for females, prevalence rates are significantly higher, ranging from 1317 to 1898 per 100,000 population, with the highest rates found in states such as Karnataka, Tamil Nadu, and Uttar Pradesh. The data indicates that females have a higher cancer prevalence rate compared to males across most regions.

Figure 3 displays the geographic distribution of cancer incidence rates in India for the year 2021. The figure presents data for both males (left side) and females (right side), allowing for a gender-based comparison of cancer prevalence across Indian states. The maps indicate that for males, the incidence rates range from 358 to 495 per 100,000 population, with higher incidence rates observed in states such as Karnataka, Andhra Pradesh, and West Bengal. For females, the incidence rates are higher, ranging from 628 to 762 per 100,000 population, with the highest rates found in Karnataka, Tamil Nadu, and Uttar Pradesh. These maps highlight regional variations in cancer incidence, with certain states exhibiting higher rates for both genders. Notably, females exhibit significantly higher incidence rates compared to males across most regions.

Figure 4 paints a concerning picture of the geographical distribution of cancer burden in India for the year 2021. The maps, divided by gender, reveal significant regional variations in DALYs caused by cancer. The maps show considerable regional variations in DALYs, reflecting the overall burden of cancer. For males, the DALYs rates range from 1193 to 4679 per 100,000 population, with the highest rates observed in states like Uttar Pradesh, Arunachal Pradesh, and West Bengal. For females, DALYs rates range from 1297 to 3022 per 100,000 population, with the highest rates in Uttar Pradesh, Madhya Pradesh, and Arunachal Pradesh. The maps highlight those certain states, particularly in the northern and North-eastern regions, experience a higher cancer burden for both genders. Additionally, while the overall range of DALYs is higher for males, certain states show comparable or even higher rates for females, indicating

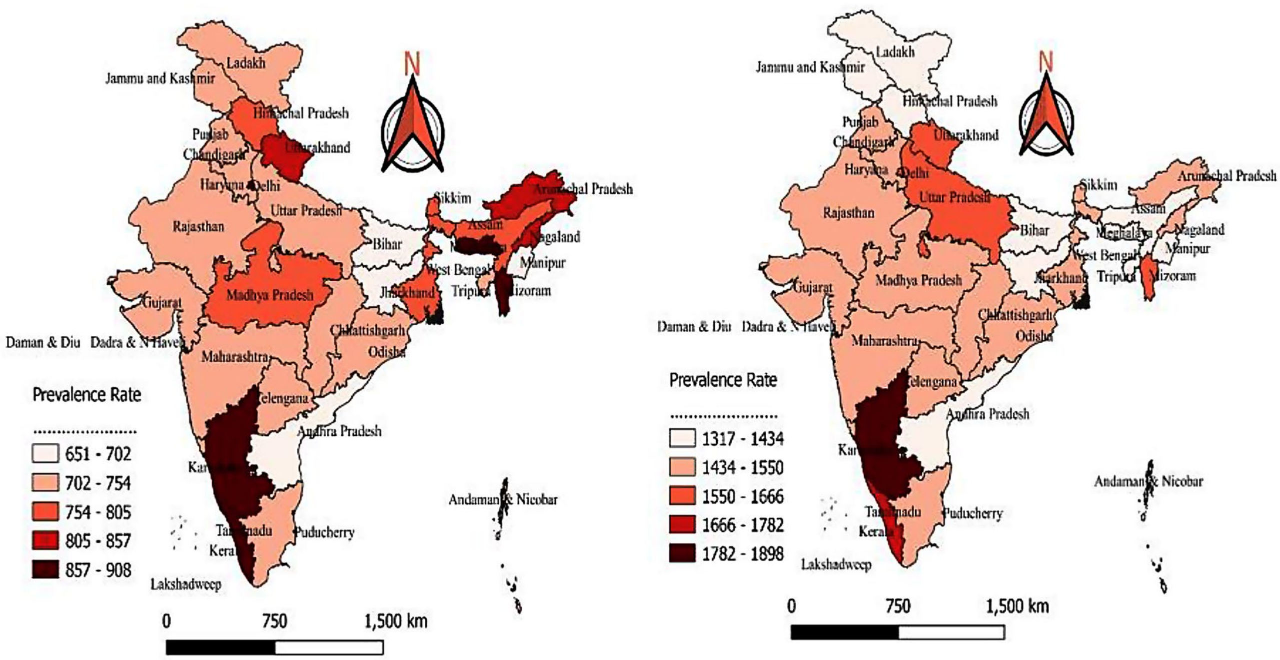

Fig. 2 Cancer prevalence rate male (left) and female (right) in India for the year 2021

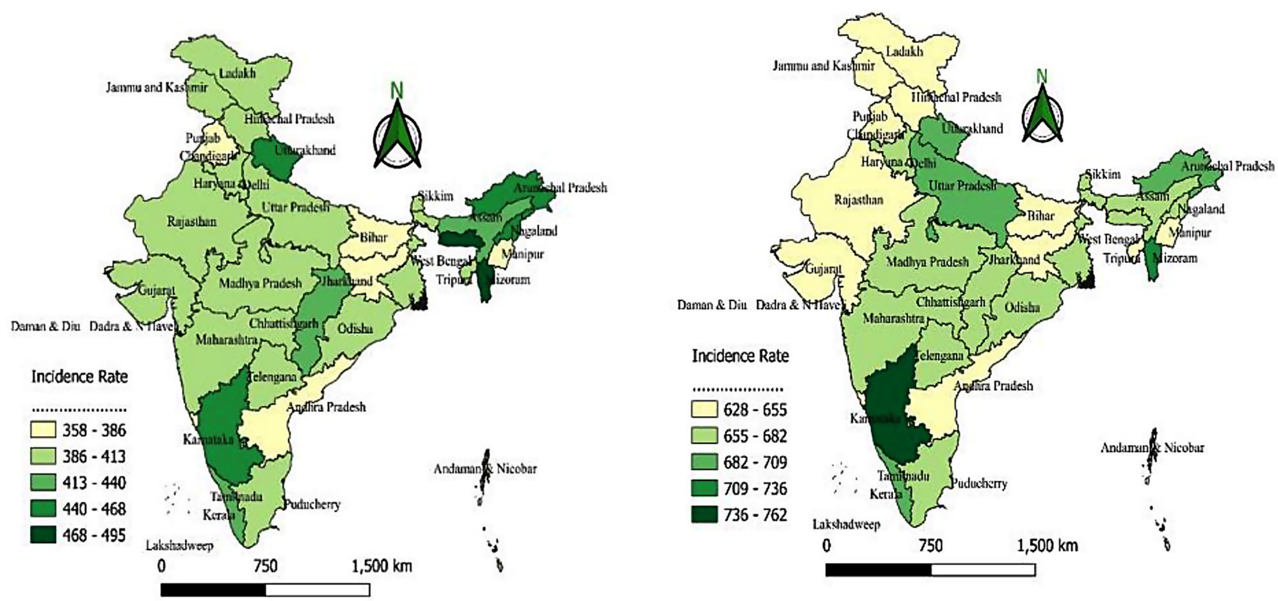

Fig. 3 Cancer incidence rate male (left) and female (right) in India for the year 2021

significant gender-specific impacts of cancer in these regions.

Figure 5 maps the stark regional variations in cancer mortality rates across Indian states for 2021. The data is presented for both males (left) and females (right), enabling a gender-specific analysis. For males, mortality rates range from 47 to 176 per 100,000 population, with states like Arunachal Pradesh, Assam, and Uttar Pradesh showing the highest burden. Females exhibit a similar trend, with rates varying between 45 and 113 per 100,000 population and the highest mortality concentrated in Arunachal Pradesh, Assam, and Uttar Pradesh. This concerning geographic pattern highlights the Northeastern states and Uttar Pradesh as areas with a significantly higher cancer mortality burden for both genders. While males generally experience higher mortality rates, the consistency in high-mortality regions across genders

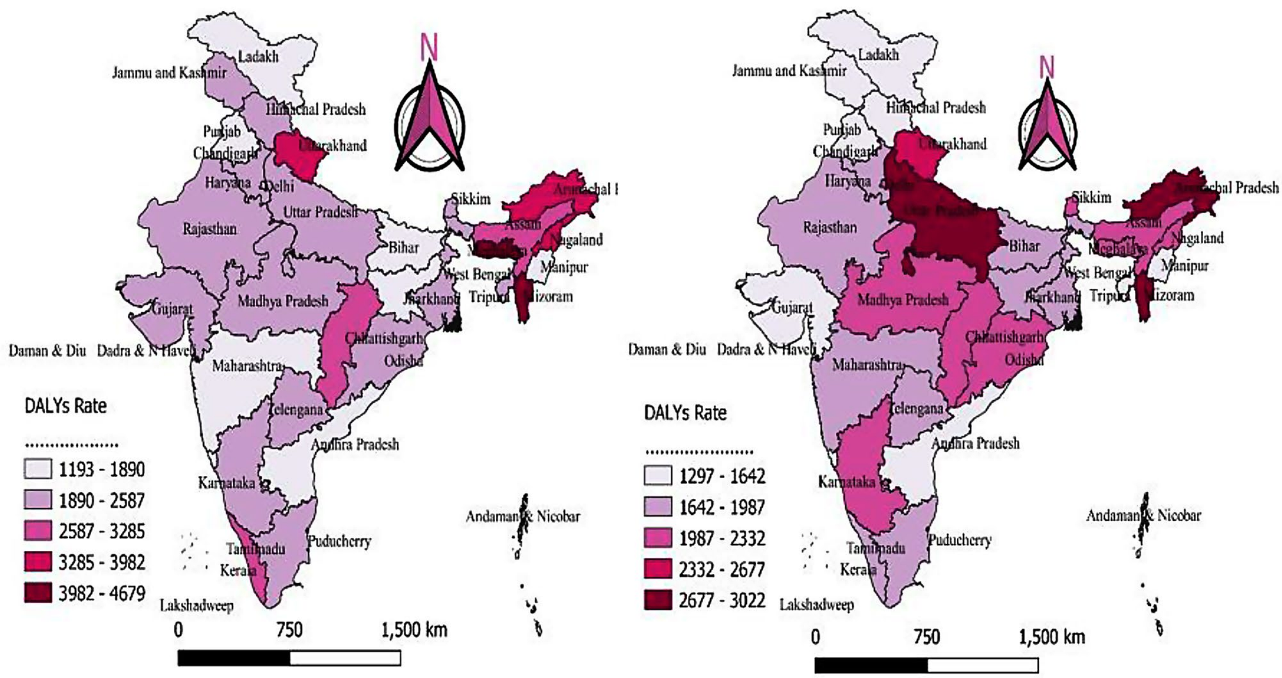

Fig. 4 Cancer DALYs rate male (left) and female (right) in India for the year 2021

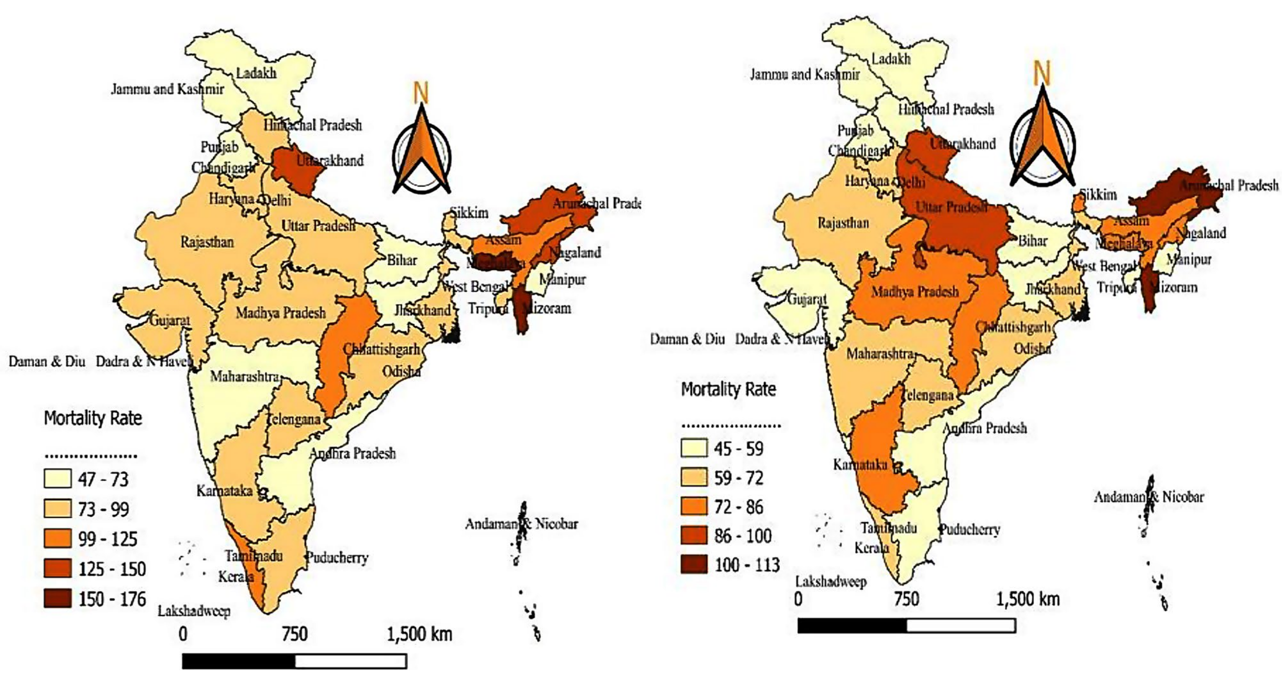

Fig. 5 Cancer mortality rate male (left) and female (right) in India for the year 2021

underscores critical public health challenges related to cancer mortality in these parts of India.

Figure 6 takes a deep dive into in prevalence, incidence, DALYs, and mortality rates of cancer trends in India from 1990 to 2021, disaggregated by total population, males, and females. The prevalence and incidence rates show a gradual increase over the years, with a marked rise starting around 2007, particularly among females, who exhibit higher rates compared to males and the total population. DALYs rates, which reflect the overall burden of cancer, show a slight decrease from 1990 to around 2005, followed by a gradual increase, stabilizing after 2010. Mortality rates remain relatively stable across the years for all groups, with a slight increase observed

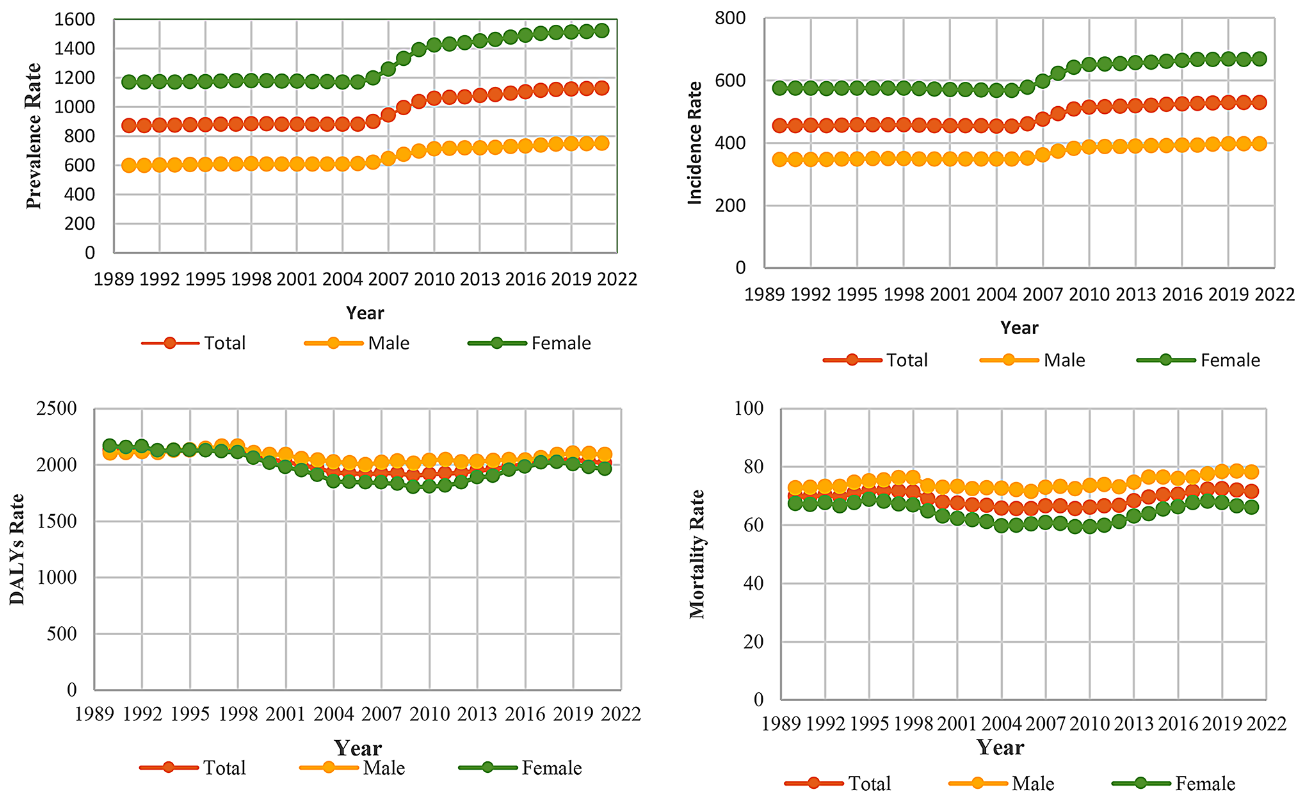

Fig. 6 Trend of Prevalence, incidence, DALYs and mortality Rate in India from the year 1990 to 2021

after 2010. Notably, females consistently exhibit higher prevalence and incidence rates, while DALYs and mortality rates show less pronounced gender differences. This data indicates an increasing cancer burden in India over the past three decades, with significant gender-specific variations, particularly in prevalence and incidence. The rising cancer burden in Fig. 6 highlights the need for time series models like ARIMA with differencing to identify underlying patterns for better forecasting and resource allocation.

As shown in Fig. 7, we implemented a differencing process. This technique involves subtracting a previous value in the time series from the current value The incidence rate of cancer also underwent examination for stationarity. The Dickey-Fuller test results indicated a potential lack of stationarity with a test statistic (t = -3.6) and a p-value of 0.04 (significant at the 5% level). To address this, we incorporated a 2-period lag (lag order=2) in the data. The analysis of the DALYs the effectiveness of this approach is confirmed by the Dickey-Fuller test. After applying the 3rd differencing, the test statistic (t = -4.74) is significant at a 5% level with a p-value of 0.01. Similar to the DALYs rate, the mortality rate required adjustments for stationarity. The Dickey-Fuller test statistic (t = -3.59) with non-stationarity (p-value=0.04). We implemented a 2-period lag to account for past values, achieving stationarity for ARIMA modelling.

By implementing these differencing approaches, we ensured that the cancer incidence, mortality, and DALYs data became stationary, satisfying a key assumption for statistical analysis like ARIMA modelling. Stationary data ensures that the mean and variance remain constant over time, allowing for more reliable modelling and forecasting.

Informed by the Autocorrelation function (ACF) and Partial Autocorrelation Function (PACF) plots in Fig. 8, a battery of ARIMA (p, d, q) models were evaluated to identify the optimal fit for cancer incidence, DALYs, and mortality rates. Cancer incidence data was best captured by ARIMA (2,2,2). This selection likely reflects the model's ability to account for both short-term dependencies (order 2 autoregressive) and longer-term influences (order 2 moving average) inherent in the incidence time series. Conversely, DALYs (ARIMA (0,3,3)) exhibited minimal autoregressive patterns (order 0), suggesting past values have a weaker influence on future DALYs. The higher-order moving average term (order 3) in the DALY model implies that past shocks or innovations may have a more persistent effect on future DALY values. Mortality rates (ARIMA (0,2,2)) also displayed minimal autoregressive patterns (order 0). The order 2 moving average term in the mortality model suggests that past trends or fluctuations in mortality rates may have a lasting impact on future values. The final selection of these specific ARIMA

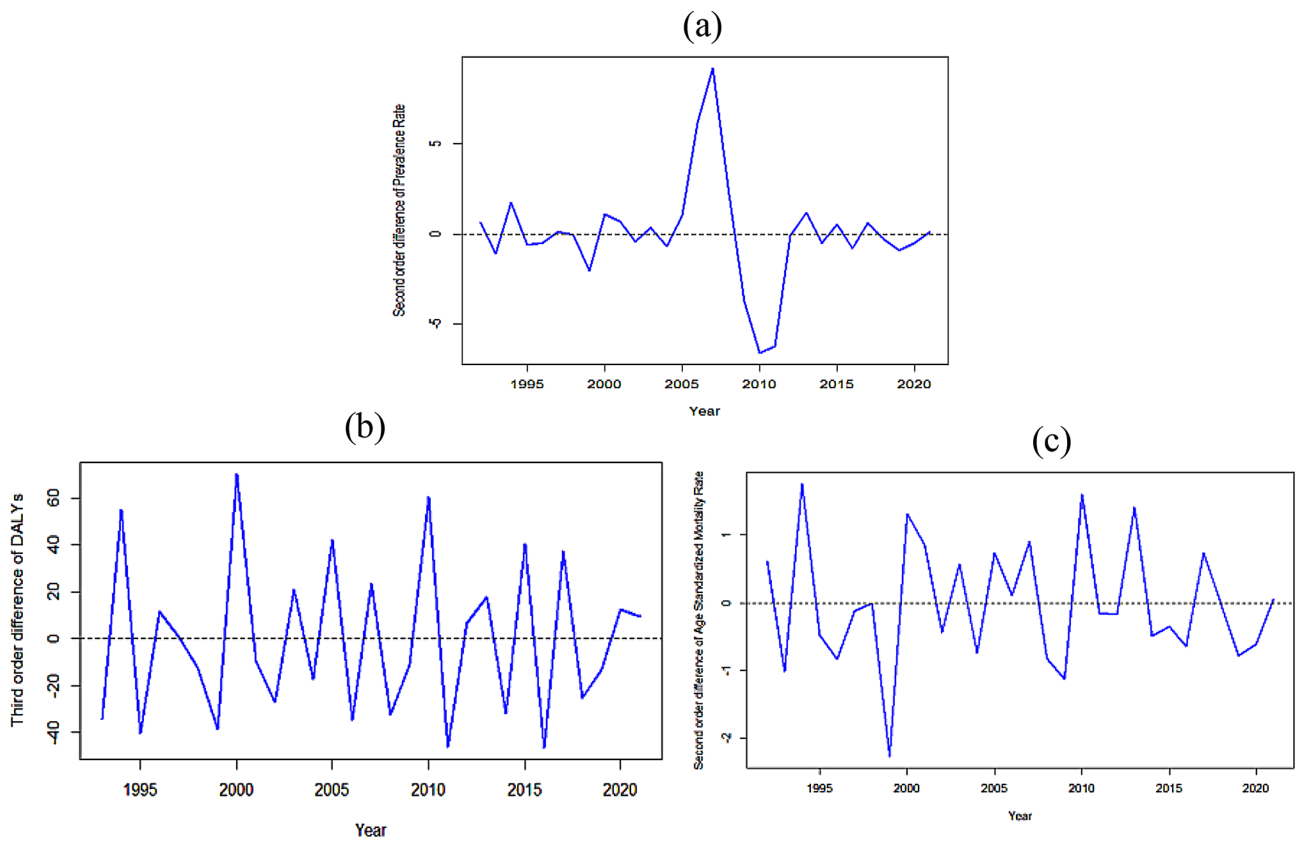

Fig. 7 Second order difference of incidence rate (**a**), third order difference of DALYs (**b**) and second order difference of mortality rate (**c**) of cancer in India

models likely involved rigorous comparison of statistical criteria, such as AIC and BIC, across all candidate models. The chosen models presumably demonstrated the lowest values for these criteria, signifying a superior fit to their respective cancer data series.

Table 4 presents the AIC and BIC values for different ARIMA models suggested for cancer incidence, DALYs, and mortality rates in India. The AIC and BIC values help determine the best-fitting model, with lower values indicating a better fit. For cancer incidence, the ARIMA (2,2,2) model has the lowest AIC value of 139.80 and BIC value of 146.46, indicating it is the best model among those considered. For DALYs, the ARIMA (0,3,3) model shows the lowest AIC value of 266 and BIC value of 271.18, making it the most suitable model. Similarly, for mortality rates, the ARIMA (0,2,2) model has the lowest AIC value of 91.96 and BIC value of 95.95, suggesting it is the best fit for the data. The Box-Pierce tests provided positive results for all three cancer rate models. The incidence rate (ARIMA (2,2,2)) showed a strong fit ($\chi^2 = 0.06$, p-value=0.79), while the mortality rate (ARIMA (0,2,2)) also indicated good fit ($\chi^2 = 1.70$, p-value=0.19). The DALY rate (ARIMA (0,3,3)) test result ($\chi^2 = 2.60$, p-value=0.10) was inconclusive, requiring further investigation to ensure the model's suitability.

From Fig. 9 we assessed the adequacy of the chosen ARIMA models (incidence rate: ARIMA (2,2,2), DALY rate: ARIMA (0,3,3), and mortality rate: ARIMA (0,2,2)) by examining the residuals' properties. This figure displays plots for standardized residuals, the autocorrelation function (ACF) of residuals, and the p-value of the Ljung-Box statistic [20]. Ideally, these plots and the p-value should not indicate any significant patterns in the residuals. Table 5 complements this analysis by presenting the estimated parameters of each model, along with their corresponding residuals and significance levels.

Table 6 provides a forecast of cancer incidence rates, DALYs rates, and mortality rates in India from 2022 to 2031, using ARIMA models with 95% confidence intervals. For the incidence rate, which follows the ARIMA (2,2,2) model, there is a steady increase from 529.40 with 95% CI (525.41-533.38) in 2022 to 549.17 with 95% CI (487.43-610.92) in 2031, widening over time. The DALYs rate, modelled by ARIMA (0,3,3), shows a decreasing trend from 2001.53 with 95% CI (1964.24-2038.82) in 2022 to 1842.08 with 95% CI (1273.57-2410.60) in 2031, suggesting an improvement in the overall cancer burden, although the confidence intervals remain substantial. The mortality rate, forecasted with the ARIMA (0,2,2) model, exhibits a slight increase from 71.52 with 95% CI (69.91–73.12) in 2022 to 73.00 with 95% CI (60.88–85.11)

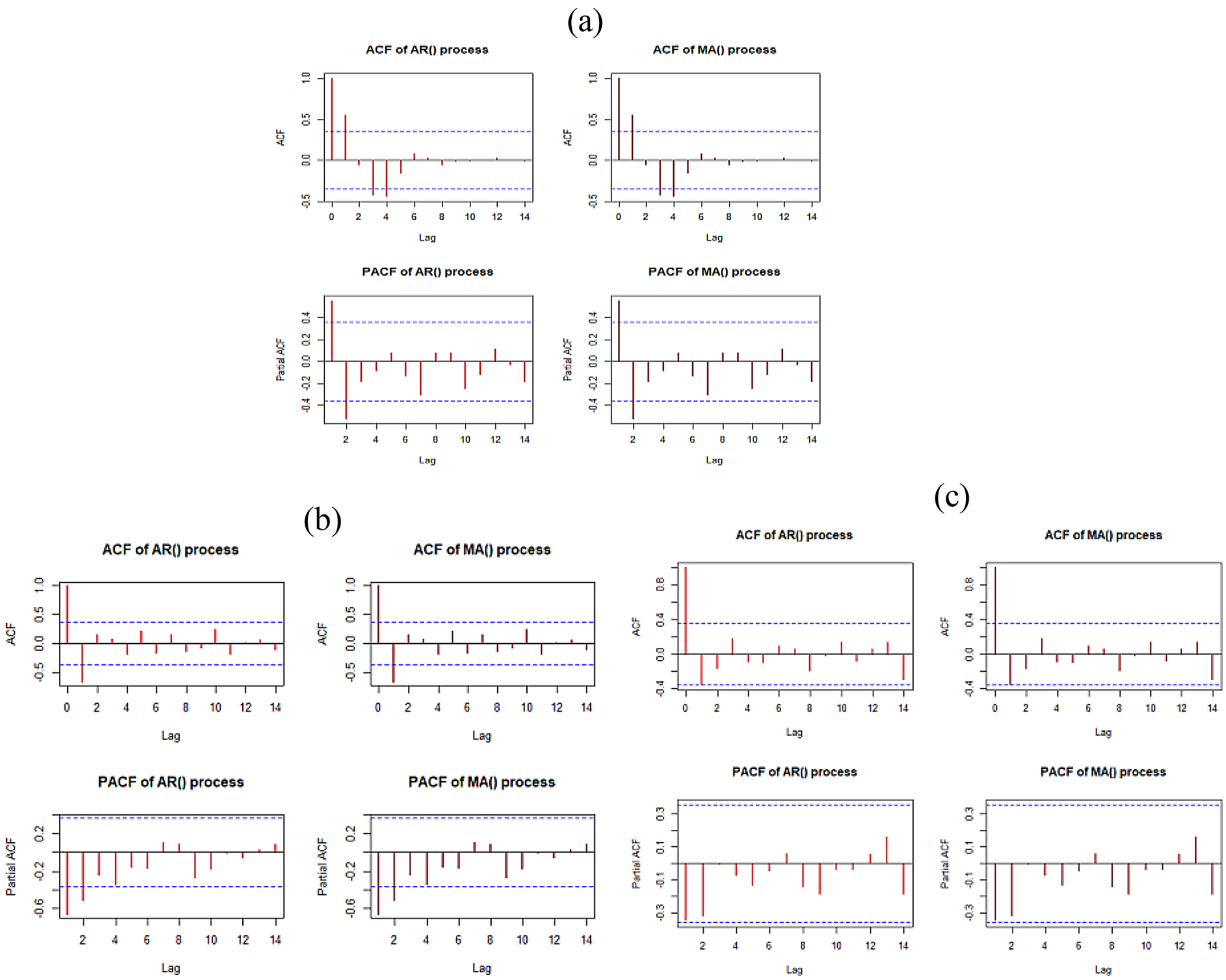

Fig. 8 ACF and PACF plot of cancer incidence (**a**), DALYs (**b**) and mortality rate (**c**) in India

in 2031, indicating increasing uncertainty over time. Overall, while incidence and mortality rates show a slight upward trend, the DALYs rate is projected to decrease, reflecting potential advancements in cancer management and treatment over the forecast period.

By analysing this table, we can see the predicted trajectory of each cancer measure over the next decade. The increasing values for incidence and mortality would be reflected by rising figures, while the decreasing DALYs would be represented by falling values. It's important to remember that the confidence interval provides a margin of error for these forecasts, indicating the potential range of actual outcomes.

Figure 10, represents forecast for cancer in India between 2022 and 2031 paints a concerning picture for incidence and mortality rates. The ARIMA models predict an upward trend in both these areas, suggesting a potential increase in cancer cases and deaths over the next decade.

However, there is a glimmer of hope in the forecast for DALYs. The DALYs model suggests a decline, which could be due to factors like improved treatment and early detection leading to better management of the disease and potentially lower long-term impact. It's important to note that these are forecasts based on statistical models, and actual trends may vary depending on advancements in cancer prevention, screening, and treatment.

The study reveals a growing cancer burden in India from 1990 to 2021, with significant increases in incidence, DALYs, and mortality, particularly from 2000 to 2021, with males experiencing substantial rises in incidence and DALYs from 2000 to 2010 and moderate increases thereafter, while females showed stable prevalence initially, followed by significant increases in incidence and DALYs from 2000 to 2010 and moderate rises in all parameters from 2010 to 2021.

Table 4 AIC and BIC values for suggested ARIMA models for cancer incidence, DALYs and mortality rate in India

Model	Likelihood	AIC	BIC	ME	RMSE	MAE	MPE	MAPE	MASE
Incidence rate									
ARIMA (0,2,0)	-74.80	151.60	152.94	0.08	3.38	2.64	-31.96	533.95	1.33
ARIMA (1,2,0)	-74.26	152.52	155.18	0.09	3.31	2.53	-33.73	546.00	1.27
ARIMA (0,2,1)	-69.87	143.75	146.41	0.10	2.67	1.89	-84.83	409.47	0.95
ARIMA (1,2,1)	-69.14	144.29	148.28	0.13	2.62	1.89	-74.94	428.37	0.95
ARIMA (1,2,2)	-68.56	145.12	150.45	0.16	2.56	1.86	-122.86	405.75	0.93
ARIMA (2,2,1)	-67.82	143.64	148.97	0.18	2.47	1.82	-96.33	373.74	0.91
ARIMA (2,2,0)	-73.11	152.22	156.21	0.09	3.17	2.28	-180.60	506.33	1.15
ARIMA (0,2,2)	-68.68	143.36	147.35	0.15	2.58	1.88	-95.80	407.36	0.94
ARIMA (2,2,2)	**-64.90**	**139.80**	**146.46**	**0.03**	**2.03**	**1.65**	**37.83**	**256.96**	**0.83**
ARIMA (3,2,0)	-72.36	152.72	158.05	0.10	3.08	2.24	-104.37	580.23	1.13
ARIMA (3,2,1)	-66.89	143.78	150.44	0.14	2.36	1.85	28.40	391.69	0.93
DALYs									
Model	**Likelihood**	**AIC**	**BIC**	**ME**	**RMSE**	**MAE**	**MPE**	**MAPE**	**MASE**
ARIMA (0,3,0)	-166.45	334.80	336.19	-3.05	109.19	90.54	300.61	1725.75	3.16
ARIMA (1,3,0)	-153.79	311.57	314.16	-2.29	67.05	52.76	440.91	647.80	1.84
ARIMA (0,3,1)	-151.68	307.37	309.96	-5.44	59.42	48.28	226.40	704.15	1.69
ARIMA (1,3,1)	-141.35	288.70	292.59	-0.53	39.13	29.91	210.35	435.51	1.05
ARIMA (2,3,0)	-143.87	293.74	297.62	-0.73	45.21	33.68	139.65	641.92	1.18
ARIMA (2,3,1)	-134.89	277.77	282.95	0.00	29.72	21.99	33.34	433.03	0.77
ARIMA (2,3,2)	-128.82	267.64	274.11	-1.71	21.19	16.05	19.90	249.34	0.56
ARIMA (0,3,2)	-138.63	283.25	287.14	-2.43	33.50	26.82	109.48	334.40	0.94
ARIMA (0,3,3)	**-129.00**	**266.00**	**271.18**	**-2.93**	**20.63**	**16.10**	**89.11**	**224.30**	**0.56**
ARIMA (2,3,3)	-127.48	266.97	274.74	-2.98	19.11	13.99	53.58	221.85	0.49
Mortality rate									
Model	**Likelihood**	**AIC**	**BIC**	**ME**	**RMSE**	**MAE**	**MPE**	**MAPE**	**MASE**
ARIMA (0,2,0)	-67.28	136.56	137.90	0.08	2.58	2.11	779.96	1132.73	1.75
ARIMA (1,2,0)	-59.72	123.43	126.10	0.08	1.95	1.53	282.16	582.00	1.27
ARIMA (1,2,1)	-48.46	102.92	106.91	0.03	1.22	0.99	-191.03	552.56	0.82
ARIMA (1,2,2)	-42.00	92.00	97.33	0.00	0.88	0.71	-192.84	393.22	0.59
ARIMA (2,2,0)	-51.90	109.81	113.81	0.05	1.45	1.16	-791.04	1424.71	0.96
ARIMA (0,2,2)	**-42.98**	**91.96**	**95.95**	**0.03**	**0.92**	**0.76**	**-124.08**	**384.89**	**0.63**
ARIMA (2,2,1)	-43.30	94.59	99.92	0.07	0.98	0.82	-505.66	740.70	0.68
ARIMA (2,2,2)	-41.13	92.26	98.92	0.06	0.85	0.68	-231.30	384.41	0.56
ARIMA (3,2,0)	-48.01	104.01	109.34	0.03	1.24	0.99	-347.80	659.30	0.82
ARIMA (3,2,1)	-42.32	94.63	101.29	0.08	0.94	0.77	-293.94	478.64	0.64
ARIMA (3,2,2)	-41.07	94.14	102.14	0.05	0.83	0.67	-271.65	422.98	0.56

Discussion

Cancer looms large as a public health threat in India. A deep dive into three decades of data from the GBD (1990–2021) reveals concerning trends. We analysed the overall cancer burden, focusing on gender and regional disparities. Males experienced substantial rises in incidence and DALYs from 2000 to 2010 and moderate increases thereafter, while females showed stable prevalence initially, followed by significant increases in incidence and DALYs from 2000 to 2010 and moderate rises in all parameters from 2010 to 2021. Our findings revealed concerning significant regional variations exist in cancer prevalence, incidence, burden (DALYs), and mortality across India. Some states consistently exhibit higher rates for both genders. Females generally have higher prevalence and incidence rates compared to males. However, the overall burden (DALYs) can be comparable or even higher for females in specific regions. The North-eastern states and Uttar Pradesh emerge as areas with a considerably higher burden of cancer for both genders, as evidenced by prevalence, incidence, DALYs, and mortality data. Although males typically have higher cancer mortality rates, females experience a significant cancer burden in some regions. Using the ARIMA model we forecast the cancer burden in India, for next decade 2022–2031 and we identified the best fit models based on minimum AIC and BIC criteria. For the incidence rate, which follows the ARIMA (2,2,2) model, there is a steady increase from 529.40 in 2022 to 549.17 in 2031, with confidence intervals widening over time. The DALYs rate,

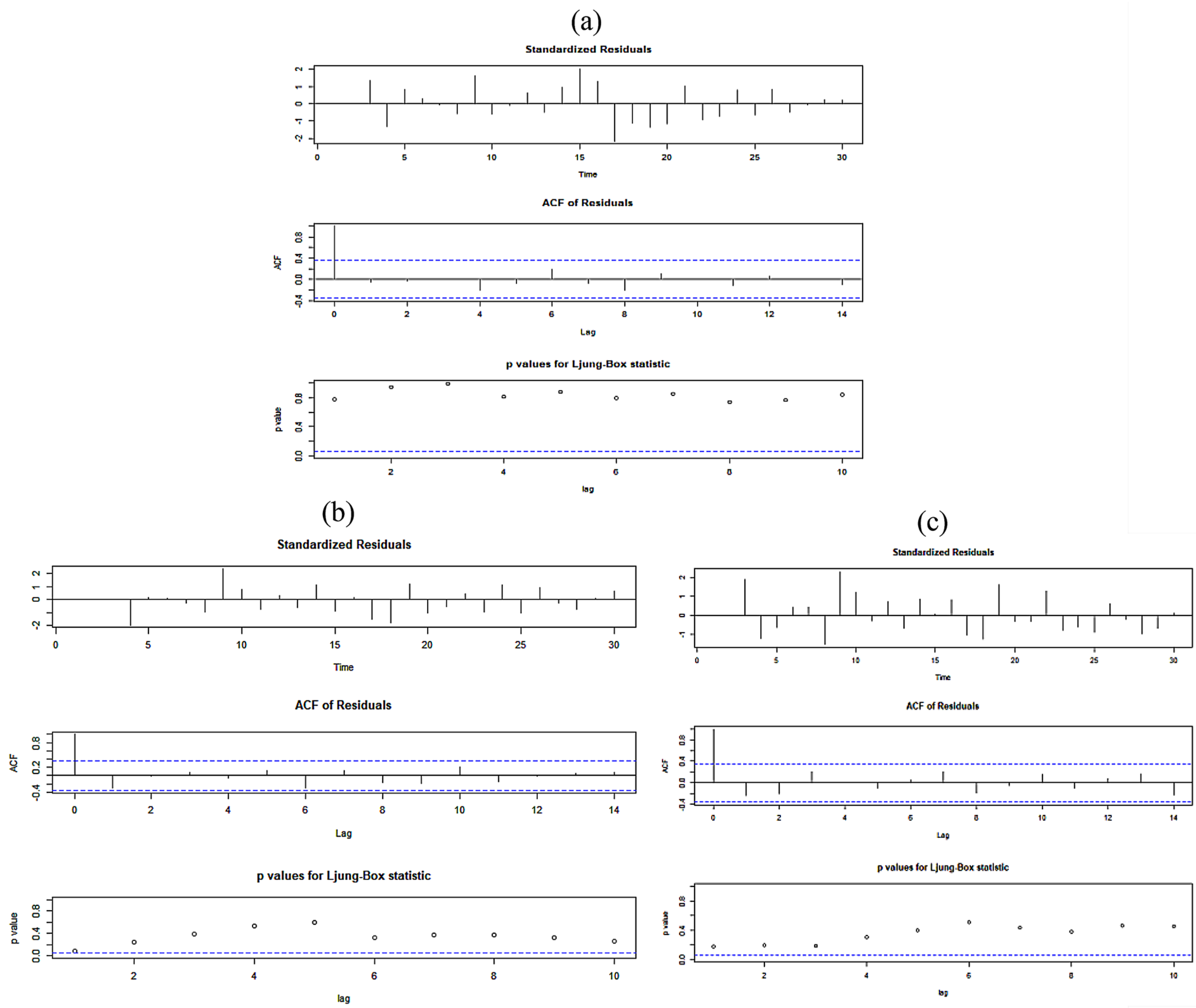

Fig. 9 Plot for residual and p-value of Ljung-Box statistics of best fitted ARIMA models of cancer incidence ARIMA (2,2,2) (**a**), DALYs ARIMA (0,3,3) (**b**) and mortality rate ARIMA (0,2,2) (**c**)

modelled by ARIMA (0,3,3), shows a decreasing trend from 2001.53 in 2022 to 1842.08 in 2031, suggesting an improvement in the overall cancer burden, although the confidence intervals remain substantial. The mortality rate, forecasted with the ARIMA (0,2,2) model, exhibits a slight increase from 71.52 in 2022 to 73.00 in 2031, with a widening confidence interval indicating increasing uncertainty over time. Overall, while incidence and mortality rates show a slight upward trend, the DALYs rate is projected to decrease, reflecting potential advancements in cancer management and treatment over the forecast period.

Our analysis, utilizing data from the GBD (1990–2021), projects a significant increase in cancer incidence and mortality rates in India. Other Studies indicate a concerning rise in cancer incidence across India, with projections estimating a jump from 1.45 million cases in 2016 to 1.75 million by 2020. Importantly, around 70% of these cases are potentially preventable through lifestyle changes and addressing modifiable risk factors like tobacco use and infections. This emphasizes the critical need for prioritizing preventive strategies to effectively manage this growing public health burden [15]. Using data from NCRP and other sources, this study projected India's cancer burden to rise from 26.7 million DALYs in 2021 to 29.8 million by 2025, with the highest burden in northern and North-eastern regions. Employing the negative binomial regression model, it identified lung, breast, and oesophagus cancers as major contributors to the burden. Using Linear Regression, NCRP (ICMR) projected that India's total cancer cases will rise from 979,786 in 2010 to 1,148,757 in 2020, with significant

Table 5 Parameters of best fit ARIMA models for cancer incidence, DALYs and mortality rate

	Incidence ARIMA (2,2,2)				**DALYs ARIMA (0,3,3)**				**Mortality ARIMA (0,2,2)**			
Parameter	Coef.	S.E.	t-statistics	p-value	Coef.	S.E.	t-statistics	p-value	Coef.	S.E.	t-statistics	p-value
AR1	0.89	0.17	5.24	< 0.01	-	-	-	-	-	-	-	-
AR2	-0.48	0.16	-3.00	< 0.01	-	-	-	-	-	-	-	-
MA1	-1.99	0.20	-9.95	< 0.01	-2.88	0.22	-13.09	< 0.01	-1.97	0.18	-10.94	< 0.01
MA2	1.00	0.20	5.00	< 0.01	2.88	0.43	6.69	< 0.01	1.00	0.18	5.56	< 0.01
MA3	-	-	-	-	-1.00	0.22	-4.54	< 0.01	-	-	-	-

increases in tobacco-related, digestive system, head and neck, lymphoid, hematopoietic, and gynaecological cancers. Breast cancer alone is expected to surpass 100,000 cases by 2020 [10].

While our study projects a concerning rise in cancer cases, other studies the projected increase in total DALYs due to breast cancer in India from 2016 to 2026 underscores the urgent need for effective primary and secondary prevention measures [24, 25]. Colorectal cancer (CRC) incidence and mortality in China significantly increased from 1990 to 2019, with males experiencing a higher burden than females. Predictions indicate this upward trend will continue over the next decade [26]. The study developed an ARIMA (2,1,0) model using Box-Jenkins methodology to accurately forecast cancer case admissions in Kenya, showing an increasing trend in incidents from 2015 to 16 onwards, aiding health facilities in decision-making [23]. Pancreatic cancer incidence and death rates in China have risen significantly from 1990 to 2019 and are projected to continue increasing through 2029, according to ARIMA model predictions. Preventive measures are necessary to address this growing disease burden [27]. Breast cancer incidence in Taiwan has doubled from 1997 to 2016 and is projected to plateau by 2031 using age-period-cohort models. The majority of future cases will involve women over 55 ages, highlighting the need for targeted prevention and screening [28].

Advancements in treatment and early detection likely play a role in the potential decline of the disease's long-term impact, underlining their importance in mitigating India's growing cancer burden. Despite the forecasted increase in cancer incidence and mortality over the next decade (2022–2031), addressing gender, age differential and regional disparities, combined with continued improvements in treatment and early detection, can help India navigate a brighter future in the fight against cancer. Understanding these scientific aspects of cancer forecasts allows India to develop effective strategies to combat these growing health challenges. Research on cancer genomics specific to the Indian population can further refine forecasts and guide targeted interventions. Public health initiatives promoting healthy lifestyles and early detection can potentially mitigate the projected rise in cases.

Consequently, by neglecting to major of risk factors, cancer types, and age groups, the study fails to pinpoint specific areas for targeted public health initiatives in India. Future research incorporating more granular, primary data from specific Indian regions would be valuable to refine our understanding of the nuanced variations in cancer burden across this diverse population.

Table 6 Forecasted cancer measures: incidence ARIMA (2,2,2), DALYs ARIMA (0,3,3), mortality ARIMA (0,2,2) for 10 years forecast with 95% confidence interval

Year	Forecasted Value								
	Incidence Rate	**Lower 95% CI**	**Higher 95% CI**	**DALYs Rate**	**Lower 95% CI**	**Higher 95% CI**	**Mortality Rate**	**Lower 95% CI**	**Higher 95% CI**
2022	529.40	525.41	533.38	2001.53	1964.24	2038.82	71.52	69.91	73.12
2023	530.97	519.79	542.15	1985.56	1915.62	2055.50	71.68	68.80	74.56
2024	533.06	513.23	552.90	1969.16	1858.35	2079.96	71.84	67.85	75.84
2025	535.45	506.98	563.92	1952.31	1793.71	2110.92	72.01	66.93	77.09
2026	537.92	501.67	574.16	1935.03	1722.30	2147.77	72.17	66.00	78.35
2027	540.34	497.44	583.23	1917.32	1644.50	2190.14	72.34	65.04	79.64
2028	542.66	494.14	591.17	1899.17	1560.56	2237.77	72.50	64.05	80.95
2029	544.88	491.52	598.24	1880.57	1470.67	2290.48	72.67	63.03	82.30
2030	547.04	489.35	604.74	1861.55	1374.97	2348.13	72.83	61.97	83.69
2031	549.17	487.43	610.92	1842.08	1273.57	2410.60	73.00	60.88	85.11

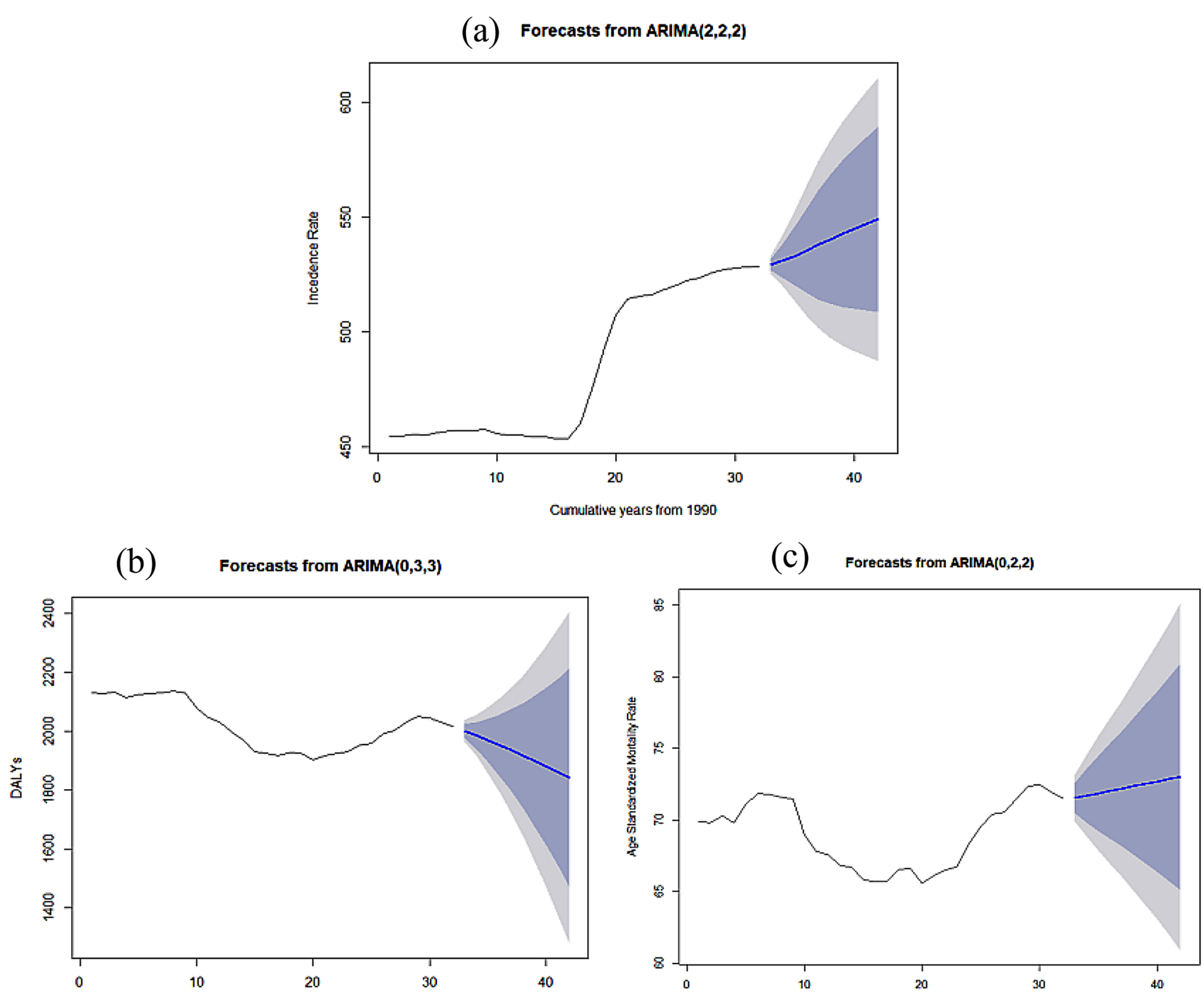

Fig. 10 Forecasted plot of the cancer incidence (**a**), DALYs (**b**) and mortality rate (**c**) for India with 95% and 80% CI

Conclusion

Cancer poses a significant public health burden in India. This study provides the complex challenge of cancer in India by examining trends, decadal shifts, gender disparities, and regional variations. By incorporating future forecasts for cancer incidence, DALYs, and mortality for the period 2022–2031, it provides a comprehensive understanding of the projected cancer burden and the need for effective interventions. This suggests that while new cases and deaths are expected to rise, improvements in treatment and early detection might reduce the long-term impact of cancer, reflected in the decreasing DALY rates. The findings underscore the pressing need for enhanced preventive measures, early detection, and improved treatment strategies to effectively manage and mitigate the growing cancer burden in India. However, a potential decline in the long-term impact, as suggested by the DALYs rate, could be attributed to improved treatment and early detection strategies. These advancements not only enhance patient outcomes but also contribute significantly to achieving India's SDG 3: Ensure healthy lives and promote well-being for all ages. Continued efforts in prevention, early diagnosis, and enhanced treatment strategies are crucial not only to manage and mitigate the growing cancer burden but also to ensure India reaches its SDG target for cancer control.

Abbreviations

ACF	Autocorrelation function
AIC	Akaike Information Criterion
AR	Autoregressive
ARIMA	Autoregressive Integrated Moving Average
BIC	Bayesian Information Criterion
CI	Confidence Interval
DALYs	Disability-adjusted life years
GBD	Global Burden of Disease
ICMR	Indian Council of Medical Research
IHME	Institute for Health Metrics and Evaluation
LC	Laryngeal cancer
MA	Moving Average
MAE	Mean Absolute Error
MAPE	Mean Absolute Percent Error
MAPE	Mean Absolute Percentage Error
MASE	Mean Absolute Scaled Error
ME	Mean Error
NCRP	National Cancer Registry Programme
PACF	Partial Autocorrelation Function
PBCRs	Population-based cancer registries
PHFI	Public Health Foundation of India
RMSE	Root Mean Square Error
RMSE	Root Mean Squared Error
SDG	Sustainable Development Goal
UTs	Union territories

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Author contributions
Conceptualization: BKP, DJ, SASDesigned the study: BKP, DJ, QSZ, SBFormal analysis: DJ, SK, MBMethodology: DJ, BKP, SHS, MRKData extraction: SR, AMGSoftware: DJ Supervision: SAS, PS, BKPValidation: BKP, QSZVisualization: AG, MRK, SRWriting—original draft: DJ, BKP, SAS, PSWriting—review & editing: PS, BKP, SR, AMG, AG, SB, SK, MB, SHSAll authors revised and approved the final manuscript.

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Data availability
This study utilized age-standardized data on cancer incidence, prevalence, DALYs, and mortality for India from the GBD study for the period 1990 to 2021. The dataset is available in the public domain for download: https://vizhub.healthdata.org/gbd-results/.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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Competing interests
The authors declare no competing interests.

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References

1. Bray F, Laversanne M, Sung H, Ferlay J, Siegel RL, Soerjomataram I, et al. Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. Cancer J Clin. 2024;74(3):229–63.
2. Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2021. (GBD 2021) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2022. https://vizhub.healthdata.org/gbd-results/. [https://vizhub.healthdata.org/gbd-results/
3. Sharma R, Abbastabar H, Abdulah DM, Abidi H, Abolhassani H, Abrehdari-Tafreshi Z et al. Temporal patterns of cancer burden in Asia, 1990–2019: a systematic examination for the global burden of Disease 2019 study. Lancet Reg Health-Southeast Asia. 2024;21.
4. Lin L, Yan L, Liu Y, Yuan F, Li H, Ni J. Incidence and death in 29 cancer groups in 2017 and trend analysis from 1990 to 2017 from the global burden of Disease Study. J Hematol Oncol. 2019;12:1–21.
5. Yancik R. Population aging and cancer: a cross-national concern. Cancer J. 2005;11(6):437–41.
6. Zhang Q-W, Wang J-Y, Qiao X-F, Li T-L, Li X. Variations in disease burden of laryngeal cancer attributable to alcohol use and smoking in 204 countries or territories, 1990–2019. BMC Cancer. 2021;21:1–12.
7. Danaei G, Vander Hoorn S, Lopez AD, Murray CJ, Ezzati M. Causes of cancer in the world: comparative risk assessment of nine behavioural and environmental risk factors. Lancet. 2005;366(9499):1784–93.
8. Mallath MK, Taylor DG, Badwe RA, Rath GK, Shanta V, Pramesh C, et al. The growing burden of cancer in India: epidemiology and social context. Lancet Oncol. 2014;15(6):e205–12.
9. Dikshit R, Gupta PC, Ramasundarahettige C, Gajalakshmi V, Aleksandrowicz L, Badwe R, et al. Cancer mortality in India: a nationally representative survey. Lancet. 2012;379(9828):1807–16.
10. Takiar R, Nadayil D, Nandakumar A. Projections of number of cancer cases in India (2010–2020) by cancer groups. Asian Pac J Cancer Prev. 2010;11(4):1045–9.
11. Jena D, Swain PK, Gandhi NC, Guthi VR, TY SS, Sreepada SS et al. Cancer Burden and trends across India (1990–2021): insights from the Global Burden of Disease study. Evid. 2024;2(3).
12. Kulothungan V, Ramamoorthy T, Sathishkumar K, Mohan R, Tomy N, Miller G et al. Burden of female breast cancer in India: estimates of YLDs, YLLs, and DALYs at national and subnational levels based on the national cancer registry programme. Breast Cancer Res Treat. 2024;205:1–10.
13. Gupta B, Ariyawardana A, Johnson NW. Oral cancer in India continues in epidemic proportions: evidence base and policy initiatives. Int Dent J. 2013;63(1):12–25.
14. Bajpai V. The challenges confronting public hospitals in India, their origins, and possible solutions. Adv Public Health. 2014;2014(1):898502.
15. Gandhi AK, Kumar P, Bhandari M, Devnani B, Rath GK. Burden of preventable cancers in India: time to strike the cancer epidemic. J Egypt Natl Cancer Inst. 2017;29(1):11–8.
16. Dhillon PK, Mathur P, Nandakumar A, Fitzmaurice C, Kumar GA, Mehrotra R, et al. The burden of cancers and their variations across the States of India: the global burden of Disease Study 1990–2016. Lancet Oncol. 2018;19(10):1289–306.
17. Mathur P, Sathishkumar K, Chaturvedi M, Das P, Sudarshan KL, Santhappan S et al. Cancer statistics, 2020: report from national cancer registry programme, India. JCO global oncology. 2020;6:1063-75.
18. Kulothungan V, Sathishkumar K, Leburu S, Ramamoorthy T, Stephen S, Basavarajappa D, et al. Burden of cancers in India-estimates of cancer crude incidence, YLLs, YLDs and DALYs for 2021 and 2025 based on National Cancer Registry Program. BMC Cancer. 2022;22(1):527.
19. Singh M, Jha RP, Shri N, Bhattacharyya K, Patel P, Dhamnetiya D. Secular trends in incidence and mortality of cervical cancer in India and its states, 1990–2019: data from the global burden of Disease 2019 study. BMC Cancer. 2022;22(1):149.
20. Box GE, Jenkins GM, Reinsel GC, Ljung GM. Time series analysis: forecasting and control. Wiley; 2015.
21. Al Zomia AS, Al Zehefa IAM, Lahiq LA, Mirdad MT, Alshahrani AS, Alshahrani T, et al. Tracking the epidemiological trends of female breast cancer in Saudi Arabia since 1990 and forecasting future statistics using global burden of disease data, time-series analysis. BMC Public Health. 2024;24(1):1953.
22. Costa EM, Magalhães Rodrigues ES, de Sousa FS, Pimentel FB, Sodré Lopes MB, Vissoci JRN, et al. The Brazilian national oral health policy and oral cancer mortality trends: an autoregressive integrated moving average (ARIMA) model. PLoS ONE. 2023;18(9):e0291609.
23. Langat A, Orwa G, Koima J. Cancer cases in Kenya; forecasting incidents using Box & Jenkins Arima Model. Biomedical Stat Inf. 2017;2(2):37–48.
24. Kunnavil R, Thirthahalli C, Nooyi SC, Somanna SN, Murthy NS. Estimation of burden of female breast cancer in India for the year 2016, 2021 and 2026 using disability adjusted life years. Int J Community Med Public Health. 2016;3(5):1135–40.
25. Pillai RN, Alex A, Narassima M, Verma V, Shaji A, Pavithran K et al. Economic burden of breast cancer prevalence by 2030 in India: Projections using Autoregressive Integrated Moving Average (ARIMA) model. 2024.
26. Zhai G, Wang Y. Disease Burden of Colorectal Cancer in China from 1990 to 2019: age- and sex-specific Time trends and 10-Year Forecast. Oncol Res Treat. 2024;47(3):76–87.
27. Chen DY, Yang XY, Fan WL, Wang HX, Wang P, Hu M, et al. [Analysis and forecast of burden of pancreatic cancer along with attributable risk factors in Asia countries between 1990 and 2019]. Zhonghua Zhong Liu Za Zhi. 2022;44(9):955–61.
28. Chen YC, Su SY, Jhuang JR, Chiang CJ, Yang YW, Wu CC, et al. Forecast of a future leveling of the incidence trends of female breast cancer in Taiwan: an age-period-cohort analysis. Sci Rep. 2022;12(1):12481.

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