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Research article

Spatiotemporal trends and age-period-cohort effects in global depression incidence, 1990-2019

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Abstract: Depression is recognized as the second most significant health threat to humanity. Using data from the Global Burden of Disease Study 2019, we conduct a comprehensive analysis of global trends in depression. By employing Joinpoint regression models, we examine long-term and segmented trends in depression incidence rates across different genders and age groups from 1990 to 2019. The results reveal an upward trend in the incidence rates since 2015 among both males and females, particularly among individuals in their mid-20s and early 40s. Furthermore, through an age-period-cohort model, we assess the effects of age, period, and cohort on the incidence rates. The findings indicate a gradual decline in incidence risk among males over time, a modest post-2015 increase among females, and a decreasing risk trend for cohorts born after 1965. Together, these results illuminate the evolving global patterns of depression incidence, thereby emphasizing gender and age disparities as well as the complex interactions among age, period, and cohort effects.

Keywords: depression; global trends; epidemiology; age-period-cohort effects; socioeconomic disparities

1. Introduction

Depression is a complex disorder influenced by genetic, biological, and psychosocial factors [1]. Current treatments include pharmacotherapy, psychotherapy, social support, and lifestyle modification [2]. Early identification and intervention are essential to improve the outcomes and

prevent deterioration. The Lancet Commission on Global Mental Health and Sustainable Development emphasizes that mental health is a fundamental human right and integral to sustainable development [3,4]. The Commission calls for a greater investment in mental health services and their integration into universal health coverage. A key component of this effort is the systematic assessment of the current and evolving disease burden, which provides critical evidence for health authorities and policymakers to address public health challenges and design effective prevention strategies [4].

Over the past three decades, depression has consistently ranked among the top three causes of nonfatal health loss globally [5]. By 2030, it is projected to become the leading contributor to the global disease burden [6]. As one of the most debilitating mental disorders, depression remains a major cause of disability worldwide. In 2019, it ranked 13th among the leading causes of disability-adjusted life years (DALYs) and second for years lived with disability (YLDs) [4]. Its impact either rivals or exceeds that of other chronic diseases such as diabetes, thus highlighting its profound implications for individuals and society [7].

Previous studies have examined depression prevalence and the incidence trends in specific countries and regions [8–12]. However, comprehensive global analyses of incidence variations across age, gender, and region are scarce. Moreover, the effects of age, period, and cohort on the depression incidence remain incompletely understood. This study aims to address these gaps by analyzing long-term global trends in the depression incidence and the influence of age, period, and cohort effects, stratified by gender. Using data from the Global Burden of Disease Study 2019 (GBD 2019), we apply an age-period-cohort (APC) framework. Additionally, we examine the relationship between the sociodemographic Index (SDI) and the global burden of depression, including DALYs, YLDs, and years of life lost (YLLs), along with their spatiotemporal characteristics. The findings provide an updated evidence base on the global burden of depression and support the formulation of evidence-based public health policies and interventions.

2. Method

2.1. Data source and collection

Our study relies on data from the GBD database, which covers diseases and injuries across five SDI regions, 204 countries and territories, and spans a time period from 1990 to 2019. The dataset includes key metrics like incidence rate, mortality rate, prevalence, YLD, YLL, and DALYs for various conditions. Specifically focusing on depression, we extract relevant data from 1990 to 2019, thereby considering four categorical variables (country, region, gender, and age group), along with three numerical variables, the disease incidence rate, prevalence, and age-standardized incidence rate. All data are sourced from the Global Health Data Exchange website (http://ghdx.healthdata.org).

2.2. Joinpoint regression model

A Joinpoint regression analysis [13] allows grid search methods for model fitting in discrete locations, thereby detecting trends in each line segment and overall lines, whether increasing or decreasing with statistical significance using the average annual percent change (AAPC). The AAPC over any fixed interval is calculated using a weighted average of the slope coefficients of the underlying joinpoint regression line. The number of Joinpoints starts from 0 and is increased to test if

the addition of Joinpoints significantly improves the fitness of model. The analyses were performed using the Joinpoint statistical software (version 4.9.1.0; National Cancer Institute, USA). Denote b_i as the slope coefficients for each segment in the desired range of years, θ_i^2 as the estimate variance of b_i, w_i as the length of each segment in the range of years, $\overline{b_i}$ as the normalized weight, and z_α as the α^{th} quantile of the standard normal distribution; then,

$$\mathrm{AAPC} = (e^{\frac{\sum w_i b_i}{\sum w_i}} - 1) * 100.$$

An approximate $100(1-\alpha)\%$ confidence interval is $(\mathrm{AAPC}_{\mathrm{L}(\alpha)}, \mathrm{AAPC}_{\mathrm{U}(\alpha)})$, where

$$\mathrm{AAPC}_{L(\alpha)} = \{\exp[\log((\mathrm{AAPC}/100)+1) - z_1 - \alpha/2\sqrt{\sum \bar{w}_i{}^2\sigma_i^2}] - 1\} * 100,$$
$$\mathrm{AAPC}_{U(\alpha)} = \{\exp[\log((\mathrm{AAPC}/100)+1) + z_1 - \alpha/2\sqrt{\sum \bar{w}_i{}^2\sigma_i^2}] - 1\} * 100.$$

Additionally, in the construction of the model equation, a network search method is employed to identify the positions and quantity of all possible segmented nodes on the curve. Subsequently, using the least squares method, the sum of squared errors and mean squared errors (MSE) are calculated for all possible combinations of the observed and fitted values. Then, the pattern with the minimum MSE is selected as the optimal segmentation point, thereby dividing the long-term trend of the disease into several short-term trend intervals. Furthermore, as more connection points are added, Monte Carlo permutation tests are conducted to assess the significance of each connection point, thus facilitating model optimization.

2.3. Age-period-cohort model

The age-period-cohort (APC) model [14,15] is a frequently employed research tool in epidemiology, demography, and related fields. Grounded in the Poisson distribution, this model decomposes the target variable across three dimensions: age, period, and cohort. This approach allows for a nuanced exploration of the independent effects of these factors on the disease incidence or mortality rates. The general mathematical expression for the APC model is given by the following:

$$\log(\lambda_{ijk}) = \mu + \beta_1 \mathrm{age}_i + \beta_2 \mathrm{period}_j + \beta_3 \mathrm{cohort}_k + \gamma_{ijk},$$

where, $ln(\lambda_{ijk})$ represents the natural logarithm of the disease incidence rate, where the intercept denotes the reference level of disease hazard, β_1, β_2, and β_3 capture the age, period, and cohort effects, respectively, and γ_{ijk} signifies the error term or residual. It is crucial to note that severe multicollinearity ($\beta_1+\beta_2+\beta_3$) exists among the age, period, and cohort in this model. The ordinary least squares and maximum likelihood estimation methods struggle to yield a unique solution for the logarithmic linear regression equation under such circumstances. Therefore, constraints must be applied to the model's parameters to obtain estimations. However, due to varying constraints, the model may yield countless solutions, thus presenting the "non-identifiability" challenge of the APC model.

This study employs the estimable function method for parameter estimation. Introduced by Holford (1983) [16] and Clayton (1987) [17], this method orthogonally decomposes the age, period, and cohort effects into linear and nonlinear components as follows:

$$\log(\lambda_{ijk}) = \mu + \beta_1^{(L)}\text{age}_i + \beta_2^{(L)}\text{period}_j + \beta_3^{(L)}\text{cohort}_k + \beta_1^{(N)}\text{age}_i + \beta_2^{(N)}\text{period}_j + \beta_3^{(N)}\text{cohort}_k + \gamma_{ijk}.$$

Here, $\beta_1^{(L)}$, $\beta_2^{(L)}$, and $\beta_3^{(L)}$ represent the linear components of the age, period, and cohort effects, thus reflecting the linear trends at a specific point, known as the slope. $\beta_1^{(N)}$, $\beta_2^{(N)}$, and $\beta_3^{(N)}$ signify the nonlinear components, also termed as deviations. In this context, the combination of deviations and slopes is identifiable, making the age, period, and cohort effects recognizable. Furthermore, we extract the drift term as a separate parameter and divide the model into several parts as follows:

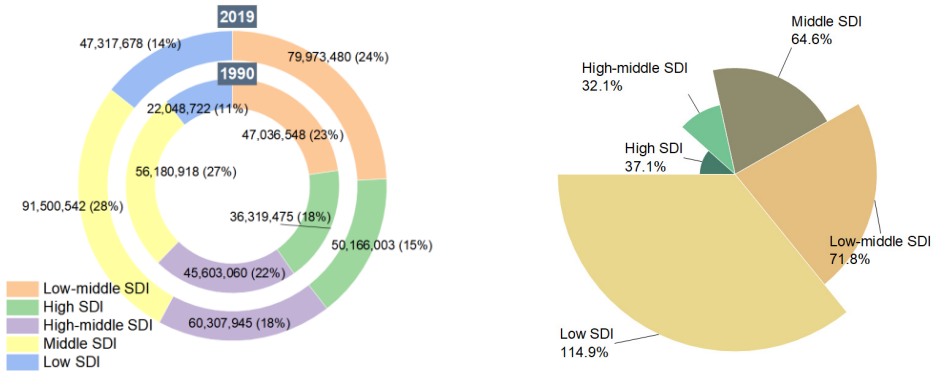
$$\log(\lambda_{ijk}) = \mu + \beta_1^{(L)}\text{age}_i + \beta_2^{(L)}\text{period}_j + \beta_3^{(L)}\text{cohort}_k + \text{drift} + \beta_1^{(N)}\text{age}_i + \beta_2^{(N)}\text{period}_j + \beta_3^{(N)}\text{cohort}_k + \gamma_{ijk}.$$

Here, the age effects denote the expected age-specific incidence rate adjusted for the period effects within the reference cohort, thus essentially representing the longitudinal incidence rates. Drift is the linear trend of the cohort effects, while $\beta_2^{(L)}$ and $\beta_3^{(L)}$ represent the detrended period and cohort effects, also termed as the period deviation and cohort deviation, respectively.

3. Results

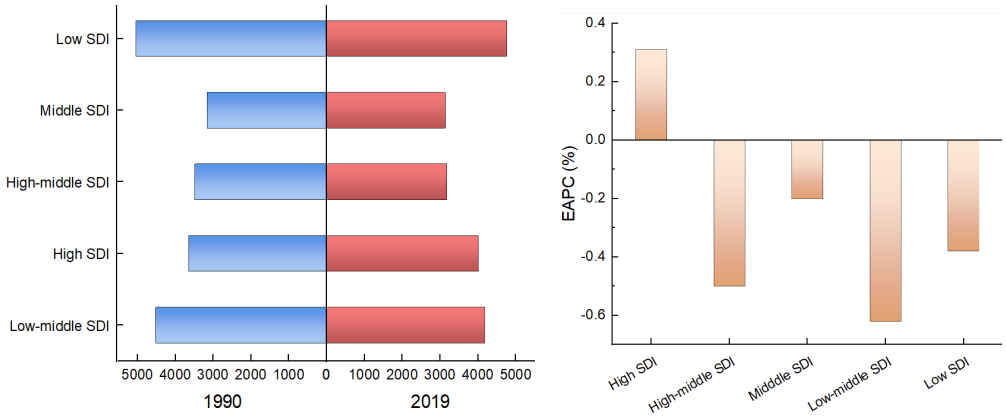
3.1. Trends in the incidence rates worldwide from 1990 to 2019

In this subsection, we present a descriptive statistical analysis of the global burden of depression. Initially, the annual growth rates of depression cases and annual percentage changes in age-standardized incidence rates were calculated to summarize the descriptive statistics across five SDI regions, 30 geographical areas, and 204 countries and territories from 1990 to 2019. Subsequently, the temporal trends in the incidence rates by sex and age group were preliminarily analyzed at the global level over the same period. As illustrated in Figure 1, the number of depression cases consistently increased across all five SDI regions between 1990 and 2019. The low SDI region exhibited the most pronounced growth, followed by the low-middle SDI region. In contrast, the high SDI region demonstrated the smallest increase, with a growth rate approximately 80 percentage points lower than that of the low SDI region. Globally, the total number of depression cases rose from 1.822 billion in 1990 to 2.902 billion in 2019, thus indicating a substantial and sustained upward trend. Figure 2 displays the age-standardized incidence rate (ASR) and estimated annual percentage change (EAPC) across the five SDI regions from 1990 to 2019. Notably, in 2019, the low SDI region had the highest ASR, whereas the high SDI region exhibited a moderate increase in incidence during the study period. However, at the global level, the ASR for depression showed an overall declining trend.



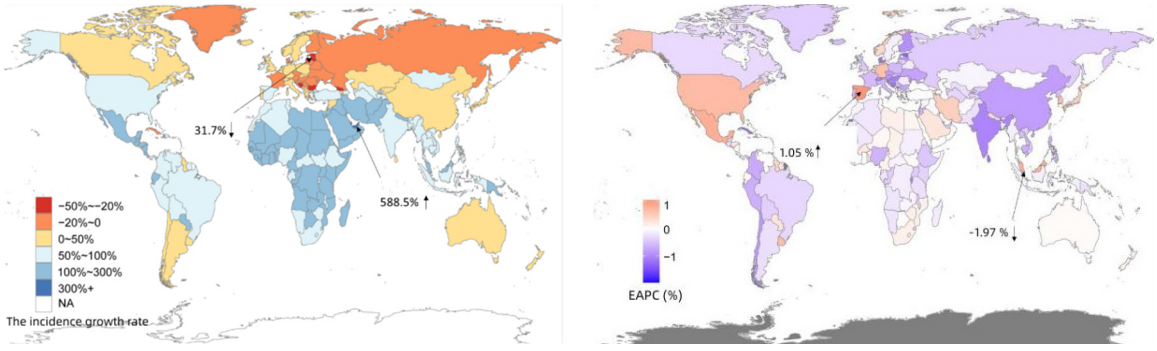
(a) (b)

Figure 1. The incidence (a) and its growth rate (b) of depression across five SDI regions from 1990 to 2019.



(a) (b)

Figure 2. The ASR (a) and EAPC (b) of depression across five SDI regions from 1990 to 2019.



(a) (b)

Figure 3. The growth rate (a) and EAPC (b) of depression incidence from 1990 to 2019 among 204 countries.

Figure 3(a) shows the growth rates of depression incidence worldwide from 1990 to 2019 among 204 countries. Qatar exhibited the highest growth rate at 481.4%, followed by the United Arab Emirates and Equatorial Guinea, with rates of 242.1% each. Among the 204 countries, 24 showed a declining trend in depression incidence, with Latvia experiencing the most substantial decrease at 31.7%, followed by Bosnia and Herzegovina (29.7%) and Estonia (27%). Figure 3(b) shows the global EAPC among the 204 countries and regions from 1990 to 2019, where 63 countries showed an upward trend, 5 countries remained unchanged, and 136 countries exhibited a declining trend. Spain had the highest EAPC at 1.05%, followed by Mexico at 0.8%. The country with the smallest EAPC was Singapore at –1.97%, thus indicating the most significant decrease in the ASR, followed by Estonia with an EAPC of –1.35%.

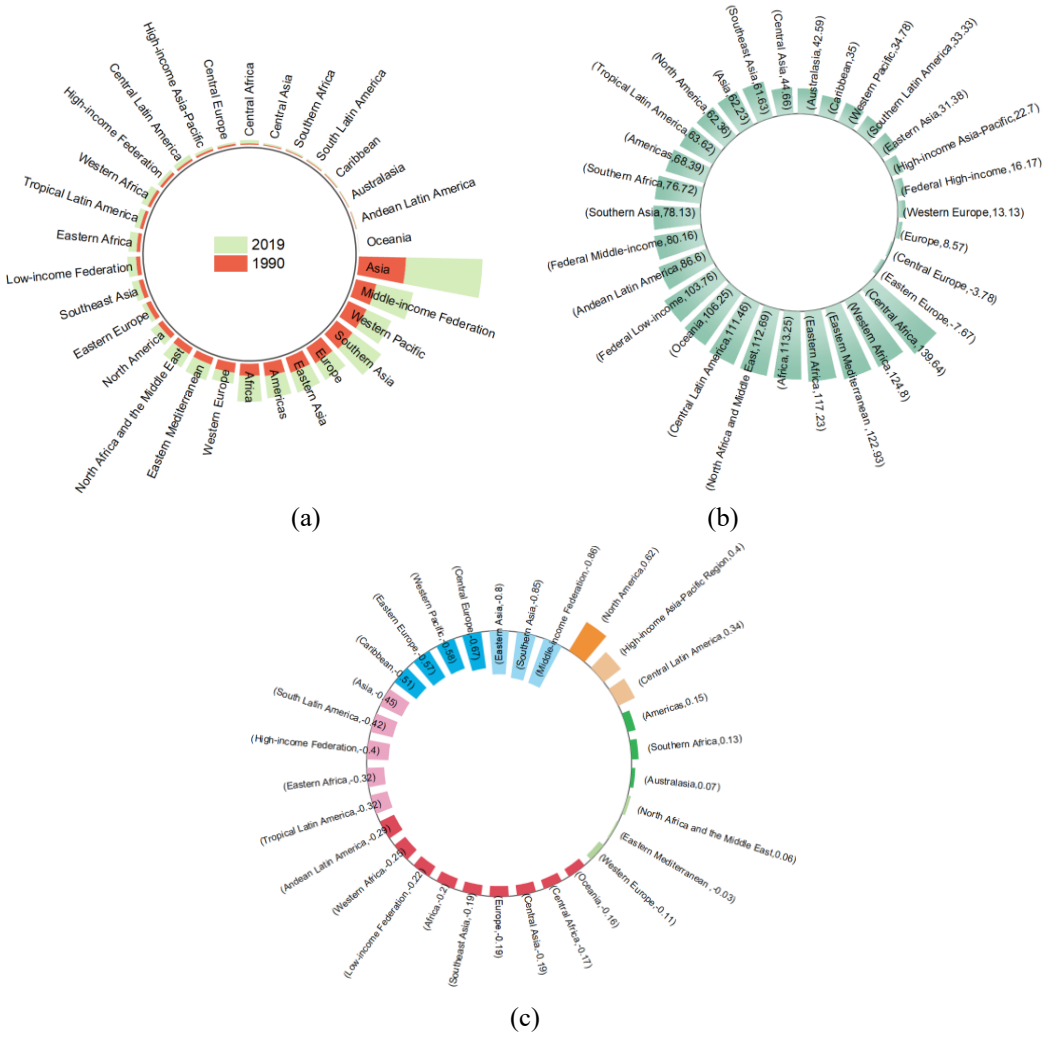


Figure 4. The incidences, growth rates (%) and EAPC (%) in 30 geographical areas during 1990 and 2019.

Figure 4 provides detailed information on the incidence and depression trends across 30 geographical areas. In both 1999 and 2019, Asia exhibited the highest incidence of depression (Figure 4(a)). Notably, among these 30 regions, 28 experienced a significant increase in the depression incidence, with the exceptions of Central and Eastern Europe, where negative growth rates were

observed at –3.78% and –7.67%, respectively (Figure 4(b)). The most substantial increase was observed in Central Africa (139.64%), followed by Western Africa (124.8%). The high-income North America region demonstrated a significant upward trend with an EAPC of 0.62%, followed by the high-income Asia-Pacific region with an EAPC of 0.4%. In contrast, the smallest increase was observed in North Africa and the Middle East, where the EAPC was only 0.06%. On the other hand, regions that indicated a decrease in the ASR of depression encompass the Eastern Mediterranean, Western Europe, Oceania, Central Africa, Central Asia, Europe, Southeast Asia, Africa, low-income Federation, Sub-Saharan Africa, Andean Latin America, Sub-Saharan Africa, Tropical Latin America, high-income Federation, Southern Latin America, Asia, the Caribbean, Eastern Europe, the Western Pacific, Central Europe, East Asia, South Asia, and the middle-income Federation. Among these, the most significant decline is observed in the middle-income Federation, with an EAPC of -0.86%, followed by South Asia with an EAPC of –0.85%.

In Figure 5, we elucidate the enduring trends in the ASR of depression across distinct gender cohorts spanning from 1990 to 2019. Our findings uncover persistent and noteworthy disparities between females and males, with females consistently exhibiting elevated rates. Moreover, discernible variations manifest in both the trajectory and magnitude of the incidence rates across distinct temporal epochs. Notably, a substantial decline in the incidence rates was observed from 2005 to 2010 (for males, a reduction from 2907.596 per 100,000 to 2697.628 per 100,000; for females, a decline from 4729.32904 per 100,000 to 4381.19435 per 100,000), while in other periods, rates either ascend or descend at a more gradual pace.

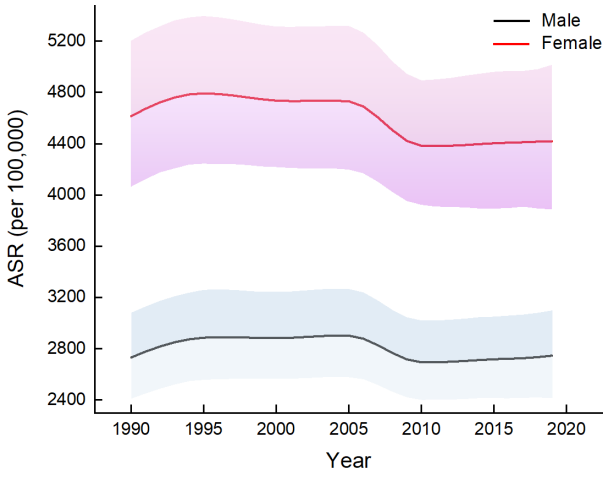


Figure 5. The ASR trend of depression by gender from 1990 to 2019.

Different age groups demonstrated distinct trends in the incidence rates over the 30-year period, as illustrated in Figure 6. For instance, the 10–14 and 15–19 age groups exhibited relatively stable trends, while other age groups experienced notable fluctuations. Notably, in the period from 2010 to 2015, the incidence rates for age groups ranging from 25–29 to 65–69 witnessed a decline, with the most significant decreases observed in the 30–34 years and 40–44 years groups, decreasing by 7.178% and 5.528%, respectively. The incidence rates for individuals aged 75–79 years and 80–84 years exhibited a consistent decline from 1990 to 2000, but experienced an upward trend from the early 21st

century to 2015, and even continued to rise for the 80–84 years age group until 2019. This underscores the impact of an aging society on the mental well–being of the elderly.

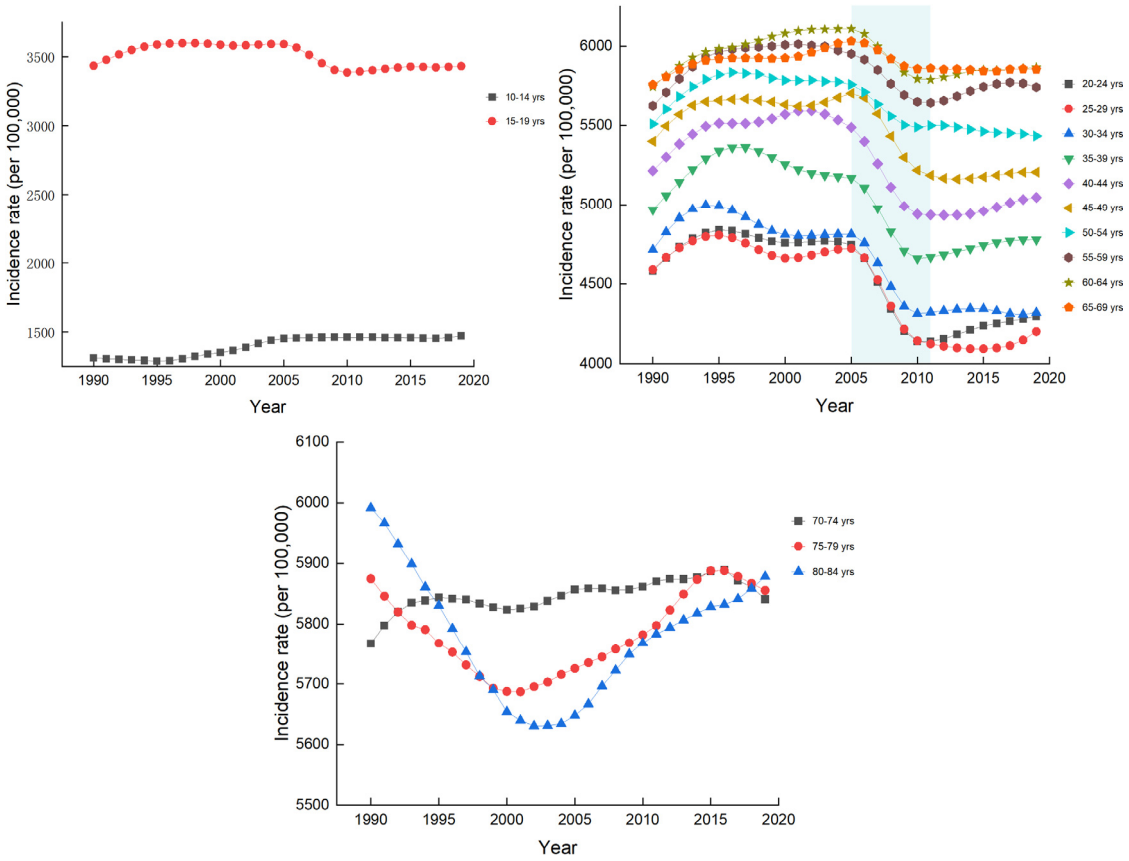


Figure 6. Age-specific incidence rates for depression from 1990 to 2019.

3.2. Joinpoint Regression Analysis of Depression Incidence Rates

We utilized the Joinpoint regression model to analyze the age-standardized depression incidence rates across annual intervals throughout the entire observational period. The objective was to offer a scientifically rigorous depiction of changing trends in the depression incidence across different time periods and demographic groups. Due to a limited yearly data availability and the non-normal distribution of the data, the analysis employed the non-linear regression equation within the Joinpoint model. This approach calculates the annual percentage change and average annual percentage change in the age-standardized depression incidence rates, thus quantifying temporal trends. Positive values denote increasing trends, while negative values indicate decreasing trends. If the model identifies a connection point count of 0, the annual percentage change is equivalent to the average annual percentage change. We conducted a detailed analysis of the long-term and segmented trends in the ASR of depression for different gender groups from 1990 to 2019. As shown in Table 1, over the 30-year period, there were a total of four Joinpoints for males, which occurred in 1994, 2001, 2005, and 2010. Additionally, the females' ASR experienced four distinct turning points, which occurred in 1994, 2006, 2009, and 2012. The segmented regression models for males and females are shown in (1) and (2), respectively.

Table 1. Joinpoint regression parameter estimates for ASR in males.

Gender	Parameter	Joinpoint	Estimate	Standard Error	T-value	P-value
Male	β_0	—	–18.324	0.9802	–18.691	< 0.001
	β_1	—	0.0132	0.0005	26.787	< 0.001
	δ_1	1994	–0.013	0.0006	–23.800	< 0.001
	δ_2	2001	0.002	0.0008	2.887	0.0107
	δ_3	2005	–0.0185	0.0009	–20.719	< 0.001
	δ_4	2010	0.0185	0.0005	37.755	< 0.001
	β_0	—	–9.403	1.6445	–5.718	< 0.001
	β_1	—	0.009	0.0008	10.858	< 0.001
Female	δ_1	1994	–0.011	0.0008	–12.513	< 0.001
	δ_2	2006	–0.020	0.0024	–8.277	< 0.001
	δ_3	2009	0.020	0.0034	5.779	< 0.001
	δ_4	2012	0.003	0.0024	1.435	0.171

$$y = \begin{cases} e^{(-18.324+0.0132x)}, & 1990 \le x < 1994, \\ e^{(7.598+0.0002x)}, & 1994 \le x < 2001, \\ e^{(3.596+0.0022x)}, & 2001 \le x < 2005, \\ e^{(40.6885-0.0163x)}, & 2005 \le x < 2010, \\ e^{(3.5035+0.0022x)}, & 2010 \le x \le 2019, \end{cases} \quad (1)$$

and

$$y = \begin{cases} e^{(-9.403+0.009x)}, & 1990 \le x < 1994, \\ e^{(12.531-0.002x)}, & 1994 \le x < 2006, \\ e^{(52.651-0.022x)}, & 2006 \le x < 2009, \\ e^{(12.471-0.002x)}, & 2009 \le x < 2012, \\ e^{(6.435+0.001x)}, & 2012 \le x \le 2019. \end{cases} \quad (2)$$

Table 2 delineates the APC within distinct time intervals and the AAPC spanning three decades for males. The ASR of depression among males on a global scale manifested an ascending trajectory in the 1990–1994, 2001–2005, and 2010–2019 periods, with annual percentage changes of 1.33%, 0.23%, and 0.23%, respectively. Significantly, during the interval 1994–2001, there was a discernible absence of any distinct trend in the age–standardized incidence rates of depression among males worldwide. Subsequent to this, in the 2005–2010 period, a decreasing trend emerged, characterized by an annual percentage change of 1.61%. In summarizing the overarching trend, it is noteworthy that the average annual percentage change across the entire 1990 to 2019 timeframe was 0. This figure signifies that the age–standardized incidence rates of depression among global males did not undergo significant variations over the past 30 years.

Table 2. The APC and AAPC of depression incidence for males.

APC (%)					AAPC (%)
1990–1994	1994–2001	2001–2005	2005–2010	2010–2019	1990–2019
1.33	0	0.23	–1.61	0.23	0

Table 3 delineates the APC within distinct time intervals and the AAPC spanning three decades for males. Noteworthy trends are evident, with an ascending pattern observed during the1990–1994 (APC: 0.9%) and 2012–2019 (APC: 0.14%) periods. In contrast, a declining trajectory was apparent during the 1994–2006 (APC: –0.16%), 2006–2009 (APC: –2.16%), and 2009–2012 (APC: –0.21%) periods. The cumulative impact over the entire span from 1990 to 2019 is encapsulated by an AAPC of –0.2%. This figure underscores a gradual decline in age–standardized depression incidence rates among females, characterized by an average annual reduction of 0.2%.

Table 3. The APC and AAPC of depression incidence for females.

APC (%)					AAPC (%)
1990–1994	1994–2006	2006–2009	2009–2012	2012–2019	1990–2019
0.9	–0.16	–2.16	–0.21	0.14	–0.2

Table 4 illustrates the trends in the global depression incidence rates across different age groups over the 30-year period. The observations reveal that the incidence rate trends vary within the same age group over different periods, and there are differences in the delineation of time intervals for various age groups. For instance, the age group of 10–14 years showed distinct trends in the depression incidence rates with six different intervals identified in the years 1996, 2001, 2005, 2012, and 2017, between 1990 and 2019. Similarly, the age group of 20–24 years exhibited four different intervals in the years 1994, 2005, and 2010, over the same observational period.

Table 4. Joinpoint regression parameter estimates for age-specific incidence.

Age group	Parameter	Joinpoint	Estimate	Standard Error	T-value	P-value
10–14 years	β_0	—	12.125	0.4635	26.157	<0.001
	β_1	—	–0.002	0.0002	–10.687	<0.001
	δ_1	1996	0.014	0.0005	30.151	<0.001
	δ_2	2001	0.004	0.0008	4.671	<0.001
	δ_3	2005	–0.015	0.0007	–21.909	<0.001
	δ_4	2012	–0.002	0.0005	–4.055	0.001
	δ_5	2017	0.007	0.0014	5.103	<0.001
	β_0	—	–9.231	1.1926	–7.740	<0.001
	β_1	—	0.009	0.0006	14.585	<0.001
15–19 years	δ_1	1995	–0.009	0.0006	–14.700	<0.001
	δ_2	2006	–0.017	0.0026	–6.712	<0.001
	δ_3	2009	0.019	0.0026	7.418	<0.001
	β_0	—	–16.062	2.4821	–6.471	<0.001
20–24 years	β_1	—	0.012	0.0012	9.876	<0.001
	δ_1	1994	–0.014	0.0013	–10.804	<0.001
	δ_2	2005	–0.027	0.0013	–21.285	<0.001
	δ_3	2010	0.033	0.0013	26.090	<0.001
	β_0	—	–14.782	1.6133	–9.163	<0.001
	β_1	—	0.012	0.0008	14.402	<0.001

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Age group	Parameter	Joinpoint	Estimate	Standard Error	T-value	P-value
	δ_1	1994	–0.017	0.0009	–18.572	<0.001
25–29 years	δ_2	2001	0.011	0.0013	8.310	<0.001
	δ_3	2005	–0.034	0.0015	–22.792	<0.001
	δ_4	2010	0.026	0.0010	27.082	<0.001
	δ_5	2016	0.011	0.0014	7.415	<0.001
	β_0	—	–35.581	7.5234	–4.729	<0.001
	β_1	—	0.022	0.0038	5.855	<0.001
	δ_1	1992	–0.017	0.0053	–3.179	0.007
30–34 years	δ_2	1995	–0.015	0.0041	–3.602	0.003
	δ_3	1999	0.008	0.0019	4.307	0.001
	δ_4	2006	–0.031	0.0036	–8.737	<0.001
	δ_5	2009	0.032	0.0035	9.038	<0.001
	β_0	—	–26.108	4.1686	–6.263	<0.001
	β_1	—	0.017	0.0021	8.309	<0.001
	δ_1	1993	–0.009	0.0046	–1.879	0.083
35–39 years	δ_2	1996	–0.014	0.0041	–3.384	0.005
	δ_3	2006	–0.024	0.0039	–6.181	<0.001
	δ_4	2009	0.029	0.0055	5.203	<0.001
	δ_5	2012	0.004	0.0040	0.994	0.338
	β_0	—	–22.898	2.5688	–8.914	<0.001
	β_1	—	0.016	0.0013	12.252	<0.001
	δ_1	1993	–0.013	0.0013	–10.269	<0.001
40–44 years	δ_2	2003	–0.014	0.0024	–5.747	<0.001
	δ_3	2006	–0.016	0.0034	–4.750	<0.001
	δ_4	2009	0.024	0.0033	7.055	<0.001
	δ_5	2012	0.008	0.0024	3.353	0.005
	β_0	—	–21.452	2.4442	–8.777	<0.001
	β_1	—	0.015	0.0012	12.300	<0.001
	δ_1	1993	–0.015	0.0013	–12.371	<0.001
45–49 years	δ_2	2002	0.003	0.0012	2.536	0.025
	δ_3	2006	–0.025	0.0016	–15.987	<0.001
	δ_4	2010	0.020	0.0025	8.080	<0.001
	δ_5	2013	0.004	0.0023	1.942	0.074
	β_0	—	–23.139	4.2540	–5.439	<0.001
	β_1	—	0.016	0.0021	7.466	<0.001
50–54 years	δ_1	1992	–0.008	0.0030	–2.577	0.020
	δ_2	1995	–0.010	0.0021	–4.601	<0.001
	δ_3	2005	–0.010	0.0010	–10.298	<0.001
	δ_4	2009	0.010	0.0010	10.338	<0.001
	β_0	—	–19.324	0.7597	–25.437	<0.001
	β_1	—	0.014	0.0004	36.833	<0.001
	δ_1	1994	–0.013	0.0004	–30.748	<0.001

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Age group	Parameter	Joinpoint	Estimate	Standard Error	T-value	P-value
55–59 years	δ_2	2002	–0.006	0.0006	–9.955	<0.001
	δ_3	2006	–0.008	0.0008	–10.710	<0.001
	δ_4	2010	0.016	0.0006	28.863	<0.001
	δ_5	2017	–0.007	0.0012	–5.461	<0.001
	β_0	—	–12.869	1.0421	–12.350	<0.001
	β_1	—	0.011	0.0005	20.667	<0.001
	δ_1	1993	–0.008	0.0005	–14.098	<0.001
60–64 years	δ_2	2002	–0.005	0.0005	–9.616	<0.001
	δ_3	2006	–0.012	0.0007	–17.661	<0.001
	δ_4	2010	0.016	0.0006	24.871	<0.001
	δ_5	2014	–0.002	0.0005	–4.049	0.001
	β_0	—	–4.365	0.7682	–5.682	<0.001
	δ_1	1994	–0.006	0.0004	–14.553	<0.001
65–69 years	δ_2	2001	0.005	0.0006	7.463	<0.001
	δ_3	2005	–0.011	0.0007	–16.663	<0.001
	δ_4	2010	0.006	0.0004	17.407	<0.001
	β_0	—	–0.872	1.9549	–0.446	0.663
	β_1	—	0.005	0.0010	4.877	<0.001
	δ_1	1992	–0.004	0.0014	–2.583	0.023
70–74 years	δ_2	1995	–0.002	0.0010	–2.041	0.062
	δ_3	2001	0.002	0.0010	2.264	0.041
	δ_4	2004	–0.001	0.0009	–0.985	0.343
	δ_5	2016	–0.003	0.0005	–5.908	<0.001

Based on this information, regression equations which capture the trends in the depression incidence rates for different age groups can be formulated. For example, the regression model for the age group of 10–14 years is as follows:

$$y = \begin{cases} e^{(12.125-0.002x)}, & 1990 \le x < 1996, \\ e^{(-15.819+0.012x)}, & 1996 \le x < 2001, \\ e^{(-23.823+0.016x)}, & 2001 \le x < 2005, \\ e^{(6.252+0.001x)}, & 2005 \le x < 2012, \\ e^{(10.276-0.001x)}, & 2012 \le x < 2017, \\ e^{(-3.843+0.006x)}, & 2017 \le x < 2019. \end{cases}$$

Table 5 presents the APC for specific time intervals and the AAPC across various age groups, thus offering insights into the overall trends in the depression incidence rates. The age groups of 10–14 years, 55–59 years, 60–64 years, and 65–69 years consistently showed an upward trend in the depression incidence rates. Notably, the most substantial increase is observed in the 10–14 years age group, with an AAPC of 0.4%. Conversely, the age groups of 20–24 years, 25–29 years, 30–34 years, 35–39 years, 40–44 years, and 45–49 years exhibited a consistent decline in the depression incidence rates. The most notable decreases occurred in the 25–29 years and 30–34 years age groups, both with an AAPC of –0.3%. The age groups of 15–19 years, 50–54 years, and 70–74 years maintained a stable trend in

the depression incidence rates, with an average annual percentage change of 0. In the last five years, distinct upward trends were observed in the 10–14 years, 20–24 years, 25–29 years, 35–39 years, and 40–44 years age groups. Conversely, the 50–54 years and 70–74 years age groups exhibited noticeable downward trends. Except for the age groups of 10–14 years and 70–74 years, all other age groups experienced a significant decline in the depression incidence rates during the period 2005–2010.

Table 5. The APC and AAPC of age-specific depression incidence.

Age group	Year	APC (%)	AAPC (%)
10–14 years	1990–1996	–0.2	0.4
	1996–2001	1.2	
	2001–2005	1.6	
	2005–2012	0.1	
	2012–2017	–0.1	
	2017–2019	0.6	
15–19 years	1990–1995	0.9	0
	1995–2006	–0.1	
	2006–2009	–1.8	
	2009–2019	0.1	
20–24 years	1990–1994	1.2	–0.2
	1994–2005	–0.2	
	2005–2010	–2.8	
	2010–2019	0.5	
25–29 years	1990–1994	1.2	–0.3
	1994–2001	–0.5	
	2001–2005	0.6	
	2005–2010	–2.8	
	2010–2016	–0.2	
	2016–2019	0.9	
30–34 years	1990–1992	2.2	–0.3
	1992–1995	0.5	
	1995–1999	–0.9	
	1999–2006	–0.1	
	2006–2009	–3.2	
	2009–2019	0	
	1990–1993	1.8	
	1993–1996	0.9	
35–39 years	1996–2006	–0.5	–0.1
	2006–2009	–2.9	
	2009–2012	0	
	2012–2019	0.3	
	1990–1993	1.6	
	1993–2003	0.2	
40–44 years	2003–2006	–1.2	–0.1
	2006–2009	–2.7	

Continued on next page

Age group	Year	APC (%)	AAPC (%)
	2009–2012	–0.4	
	2012–2019	0.4	
	1990–1993	1.5	
	1993–2002	0	
45–49 years	2002–2006	0.3	–0.1
	2006–2010	–2.2	
	2010–2013	–0.3	
	2013–2019	0.2	
	1990–1992	1.6	
	1992–1995	0.8	
50–54 years	1995–2005	–0.1	0
	2005–2009	–1.1	
	2009–2019	–0.1	
	1990–1994	1.4	
	1994–2002	0.1	
55–59 years	2002–2006	–0.4	0.1
	2006–2010	–1.3	
	2010–2017	0.4	
	2017–2019	–0.3	
	1990–1993	1.1	
60–64 years	1993–2002	0.3	0.1
	2002–2006	–0.1	
	2006–2010	–1.3	
	2010–2014	0.3	
	2014–2019	0.1	
	1990–1994	0.7	
	1994–2001	0	
65–69 years	2001–2005	0.5	0.1
	2005–2010	–0.6	
	2010–2019	0	
	1990–1992	0.5	
	1992–1995	0.1	
	1995–2001	–0.1	
70–74 years	2001–2004	0.1	0
	2004–2016	0.1	
	2016–2019	–0.2	

3.3. Age-period-cohort model

In the progression of a medical condition, an array of objective factors, including the patient's age, life period, birth cohort, and societal developmental stages, has the potential to influence the trend in disease incidence. Moreover, these influencing factors often exhibit intricate interactions. Traditional methods of a trend analysis typically involve plotting the disease incidence rate curves under different influencing factors. However, the influence of a specific factor on the trend may be confounded by other factors, thus rendering it challenging to provide a comprehensive explanation of

the disease incidence rate changes solely based on the plotted curves. Therefore, this subsection employs an APC model to unravel the interactions between various factors. The objective is to analyze and discuss the impact of the age, period, and birth cohort on the depression incidence rates over the 30-year period. This model, to a certain extent, mitigates and eliminates the interactive effects among these three factors, thus facilitating a more detailed and lucid discussion of the independent influences of the age, period, and birth cohort on the trend of disease incidence.

The age effects encompass variations in risk arising from changes in social status, roles, population aging, and other factors as individuals age. These effects are elucidated through a longitudinal age curve, which illustrates the expected age–specific incidence rates adjusted for period effects in the reference cohort. The visual representation of the age effects is meticulously presented in Figure 7. Spanning from 1990 to 2019, distinctive trends in global depression incidence rates for both males and females were apparent across different age groups. For global males, the incidence rates rapidly surged from the age group of 10–14 years, and reached a peak in the 20–24 years age group, thus indicating a gradual increase in depression incidence with age during this stage. Between the ages of 25–34, there was a gradual decline in the risk of depression. After the age group of 35–39, there is a subsequent increase, albeit at a slower pace. In females, the incidence rates rapidly escalated from the age group of 10–14 years to peak in the 20–24 years age group. From the age group of 30–34 onwards, there was a slow ascent, with a gentle decline observed between the two age stages. Moreover, the age effects on the depression incidence for females were significantly higher than those for males across all age groups.

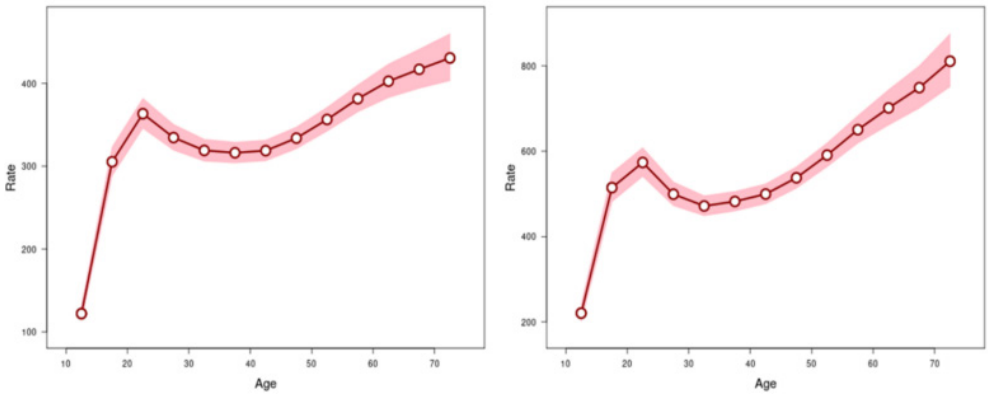

Figure 7. Age effects for global male (left) and female (right) of depression incidence rates.

The period effects refer to variations in the disease risk attributable to human-made factors, including changes in disease definitions or registrations during a specific period, advancements in medical diagnostic technologies, the introduction of specific medications, and large–scale disease screening initiatives. These objective factors are quantified by the period rate ratio (period RR), which corrects for age and cohort biases. The visual representation of period effects is meticulously presented in Figure 8. Over the entire study period, the period RR values for the depression incidence in global males consistently depict a downward trend, which is indicative of a gradual reduction in the risk of depression over time. Specifically, during the periods of 1990–1999 and 2012–2019, the decline in incidence risk was relatively slow, while in other periods, there is a more pronounced decrease. Using the reference value as the 2000–2004 period (RR = 1), the relative risk values for the periods of 1990–1994 and 1995–1999 were both greater than 1, which signify a higher incidence risk compared to the

reference period. Notably, the period of 1990–1994 exhibited the highest incidence risk (RR = 1.16). After 2004, the relative risk values for all periods were less than 1, thus indicating a lower incidence risk compared to the reference period, with the period of 2015–2019 showing the lowest risk. In contrast, the period trends for the depression incidence in global females diverged from males. The period relative risk values for females declined from 1990 to 2014, with a slight increase observed in the 2015–2019 period, thus indicating a trend of decreasing risk followed by a mild rise.

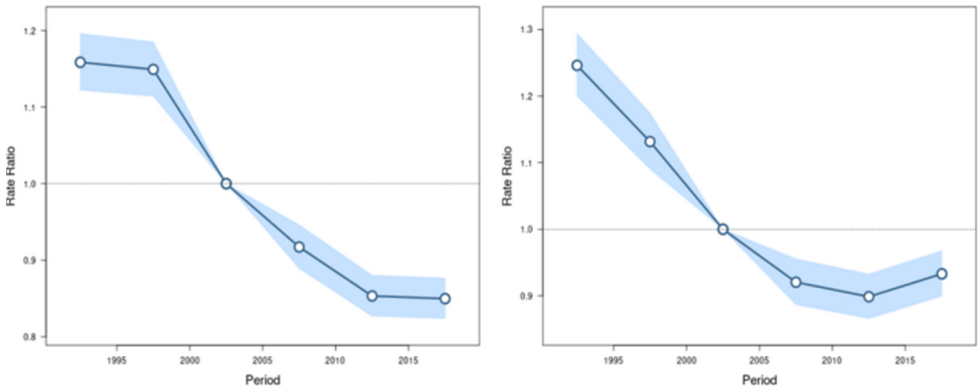

Figure 8. Period RR of depression incidence for global males (left) and females (right).

The cohort effects refer to the varying impact of exposure to certain risk factors for depression incidence or mortality across different birth cohorts. These effects reflect the influence of early experiences and social environments on individuals, which is quantified by the Cohort rate ratio (Cohort RR). This ratio represents the risk of incidence specific to a cohort compared to a reference cohort, after adjusting for age and period effects. Figure 9 illustrates that both global males and females share a similar trend in the cohort relative risk ratio for depression. Using the birth cohort of 1960 as the reference (RR = 1), the depression incidence risk for both genders peaked in cohorts born between 1920 and 1955, with relative risk ratios of 1.16 and 1.14, respectively. Following 1965, there was a decline in risk as the cohorts shifted towards later birth years, thus indicating that earlier-born cohorts had a higher relative risk of depression, while cohorts born later exhibited lower incidence rates.

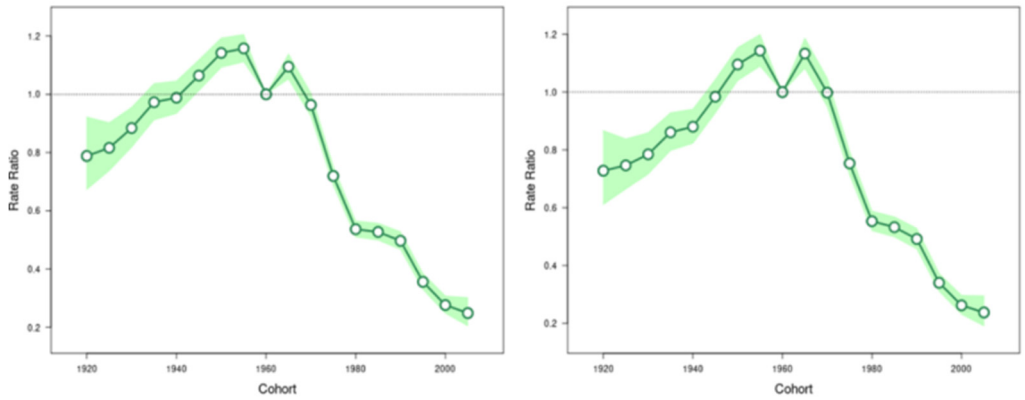

Figure 9. Cohort relative risk of depression incidence in global males (left) and females (right).

4. Discussion

This paper, grounded in data sourced from GBD2019 database spanning the years 1990 to 2019, offers an exhaustive analysis of the spatiotemporal trends in the depression incidence and the intricate influences of the age, period, and cohort factors. In 2019, regions with the highest ASR for depression were predominantly in low SDI areas, with Central Africa identified as the leading region. The estimated APC was most prominent in high SDI regions, reaching 0.31%. Regionally, the highest APC was observed in the high‐income North American region, at 0.62%. These results indicate that from 1990 to 2019, countries with lower economic development maintained higher standardized depression incidence rates. However, areas with stronger economies experienced more pronounced increases in the ASR of depression over this period.

Economically developed regions often feature highly competitive and efficiency-driven lifestyles, which may increase the susceptibility to mental health issues, including depression [18,19]. Despite broader social networks, residents in these areas may experience social isolation—a recognized risk factor for depression. In highly industrialized and urbanized settings, feelings of loneliness and a detachment from society may be more prevalent [20,21]. Moreover, work environments in economically developed regions are typically competitive, with long working hours, high work intensity, and occupational uncertainty, which further elevates depression risk. Additionally, cultural perspectives and reporting practices regarding mental health may vary by region. In some economically advanced areas, a cultural emphasis on individual success and high achievement standards may contribute to elevated psychological stress.

The results of gender-specific incidence rates from the Joinpoint regression analysis revealed distinctive trends in the age-standardized depression rates for both males and females over the past 30 years. The annual average percentage change in age–standardized depression rates for males remained at 0, thus indicating a lack of significant variation in trends during this period. Conversely, females exhibited a consistent downward trend, with an annual average percentage change of 0.2%. Segmented trends indicated a notable decrease in both the male and female age-standardized depression rates during the 2005–2010 period. However, in the last 5–10 years, a rising trend was evident in the global annual percentage change for males (0.23% between 2010–2019) and females (0.14% between 2012–2019). However, compared to the trend from 1990–1994, the upward trajectory in incidence rates for both genders has significantly slowed down.

The larger burden of females to depression compared to males is a multifaceted phenomenon with intricate determinants. Physiological factors play a pivotal role, wherein differences in hormonal levels, particularly fluctuations in estrogen levels associated with physiological cycles, may exert an impact on the psychological well–being of females [22]. Moreover, genetic and biological factors contribute, with familial history and genetic predispositions rendering females more sensitive to the risk of depression [23]. Additionally, social and cultural elements are instrumental in elucidating the heightened propensity of females towards depression. Factors such as societal roles, expectations, and gender disparities can contribute to the increased vulnerability of females to mental health issues [24]. Hormonal variations experienced by females at different life stages, including menstrual cycles, pregnancy, and menopause, further underscore the complexity of the relationship between hormonal changes and psychological health. Finally, disparities in stress responses, where females may exhibit more pronounced reactions to certain stressors, constitute another contributing factor that potentially elevates their susceptibility to depression [25]. This comprehensive analysis sheds light on the intricate

interplay of physiological, genetic, social, and psychological factors that collectively contribute to the observed gender–based differences in the prevalence of depression.

The age-specific incidence rates revealed by the Joinpoint regression analysis from 1990 to 2019 elucidated distinct trends in the depression prevalence across specific age groups. Notably, a rising trend in the depression incidence was observed among children aged 10–14 and individuals aged 55 and above. Conversely, the incidence rates among the middle–aged population, specifically those aged 25–34, exhibited a declining trend. Of particular concern is the evident upward trajectory in the incidence rates over the past 5 years, notably among the age groups of 10–14, 20–24, 25–29, 35–39, and 40–44. The trends were especially pronounced in young adults around 24 years old and middle–aged individuals around 40, thus signaling a growing severity in mental health concerns. These findings underscore a pressing need for attention and intervention in addressing the escalating challenges in mental well-being within these age cohorts.

This could be attributed to various factors at different life stages. Adolescents aged 10–14 undergo rapid physical and physiological changes, thus potentially impacting their mental well-being [26]. The age brackets of 20–24 and 25–29 mark the transition into adulthood and the early stages of professional careers, thus introducing new responsibilities and pressures that may elevate the risk of depression [27]. The periods of 35–39 and 40–44 might entail increased familial and occupational pressures, thus representing pivotal phases of significant life changes. These specific age ranges may be associated with distinct societal stresses, including academic pressures, professional challenges, and family responsibilities [28,29]. Thus, the increasing incidence of depression in these age groups may result from the intricate interplay of physiological, social, and psychological factors.

An analysis based on the APC model revealed intriguing patterns in the incidence rates of depression for both males and females. Notably, the age effects exhibited a similar trajectory for both genders, characterized by an initial increase, followed by a decline, and then a subsequent rise, with the most pronounced rise in the depression rates observed between the ages of 10 and 24. In terms of period effects, males demonstrated a consistent downward trend, thus signifying a diminishing risk of depression over the study period. Conversely, females displayed a nuanced trend, initially decreasing and subsequently showing a slight increase in relative risk values after 2015. The cohort effects unveiled an intriguing pattern, where both males and females experienced an elevation in relative risk values from 1920 to 1955, reached a peak, and subsequently decreased post-1965. This implies that earlier birth cohorts exhibited a higher relative risk of depression, while those born later demonstrated a lower incidence rate.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare that there is no conflict of interest.

References

1. Andrews G, Poulton R, Skoog I, (2005) Lifetime risk of depression: restricted to a minority or waiting for most?. *Br J Psychiatry* 187: 495–496. https://doi.org/10.1192/bjp.187.6.495
2. Lépine JP, Briley M, (2011) The increasing burden of depression. *Neuropsychiatr Dis Treat* 7: 3–7. https://doi.org/10.2147/NDT.S19617
3. GBD 2019 Mental Disorders Collaborators, (2022) Global, regional, and national burden of 12 mental disorders in 204 countries and territories, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. *Lancet Psychiatry* 9: 137–150. https://doi.org/10.1016/S2215-0366(21)00395-3
4. Hong C, Liu Z, Gao L, Jin Y, Shi J, Liang R, et al. (2022) Global trends and regional differences in the burden of anxiety disorders and major depressive disorder attributed to bullying victimisation in 204 countries and territories, 1999–2019: An analysis of the Global Burden of Disease Study. *Epidemiol Psychiatr Sci* 31: e85. https://doi.org/10.1017/S2045796022000683
5. GBD 2017 DALYs and HALE Collaborators, Global, regional, and national disability-adjusted life-years (DALYs) for 359 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2017: A systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 392: 1859–1922.
6. Sorrell S, (2014) *Depression: Understanding the Black Dog*, John Hunt Publishing.
7. Hays RD, Wells KB, Sherbourne CD, Rogers W, Spritzer K, (1995) Functioning and well-being outcomes of patients with depression compared with chronic general medical illnesses. *Arch Gen Psychiatry* 2: 11–19. https://doi.org/10.1001/archpsyc.1995.03950130011002
8. Prasartpornsirichoke J, Pityaratstian N, Poolvoralaks C, Sirinimnualkul N, Ormtavesub T, Hiranwattana N, et al. (2023) The prevalence and economic burden of treatment-resistant depression in Thailand. *BMC Public Health* 23: 1541. https://doi.org/10.1186/s12889-023-16477-y
9. Greenberg PE, Kessler RC, Birnbaum HG, et al. The economic burden of depression in the United States: how did it change between 1990 and 2000?. *J Clin Psychiatry* 64: 1465–1475. https://doi.org/10.4088/JCP.v64n1211
10. Andrews G, Sanderson K, Slade T, Issakidis C, (2000) Why does the burden of disease persist? Relating the burden of anxiety and depression to effectiveness of treatment. *Bull W H O* 78: 446–454. https://doi.org/10.1080/000486700536
11. Üstün TB, Ayuso-Mateos JL, Chatterji S, Mathers C, Murray CJL, (2004) Global burden of depressive disorders in the year 2000. *Br J Psychiatry* 184: 386–392. https://doi.org/10.1192/bjp.184.5.386
12. Sobocki P, Lekander I, Borgström F, Ström O, Runeson B, (2007) The economic burden of depression in Sweden from 1997 to 2005. *Eur Psychiatry* 22: 146–152. https://doi.org/10.1016/j.eurpsy.2006.10.006
13. Kim HJ, Fay MP, Feuer EJ, Midthune DN (2000) Permutation tests for joinpoint regression with applications to cancer rates. *Stat Med* 19: 335–351. https://doi.org/10.1002/(SICI)1097-0258(20000215)19:3%3C335::AID-SIM336%3E3.0.CO;2-Z
14. Wang L, Yu C, Liu Y, Wang J, Li C, Wang Q, et al. (2016) Lung cancer mortality trends in China from 1988 to 2013: New challenges and opportunities for the government. *Int J Environ Res Public Health* 13: 1052–1063. https://doi.org/10.3390/ijerph13111052

15. Rosenberg PS, Check DP, Anderson WF, (2014) A web tool for age–period–cohort analysis of cancer incidence and mortality rates. *Cancer Epidemiol Biomarkers Preve* 23: 2296–2302. https://doi.org/10.1158/1055-9965.EPI-14-0300
16. Holford TR, (1983) The estimation of age, period and cohort effects for vital rates. *Biometrics* 39: 311–324. https://doi.org/10.2307/2531004
17. Clayton D, Schifflers E, (1987) Models for temporal variation in cancer rates. II: Age-period-cohort models. *Stat Med* 6: 469–481. https://doi.org/10.1002/sim.4780060406
18. Heinz AJ, Meffert BN, Halvorson MA, Blonigen D, Timko C, Cronkite R, (2018) Employment characteristics, work environment, and the course of depression over 23 years: Does employment help foster resilience?. *Depression Anxiety* 35: 861–867. https://doi.org/10.1002/da.22782
19. Ahonen E Q, Fujishiro K, Cunningham T, Flynn M, (2018) Work as an inclusive part of population health inequities research and prevention. *Am J Public Health* 108: 306–311. https://doi.org/10.2105/AJPH.2017.304214
20. Donovan NJ, Blazer D, (2020) Social isolation and loneliness in older adults: Review and commentary of a national academies report. *Am J Geriatr Psychiatry* 28: 1233–1244. https://doi.org/10.1016/j.jagp.2020.08.005
21. Courtin E, Knapp M, (2017) Social isolation, loneliness and health in old age: A scoping review. *Health Soc Care Community* 25: 799–812. https://doi.org/10.1111/hsc.12311
22. Albert KM, Newhouse PA, (2019) Estrogen, stress, and depression: Cognitive and biological interactions. *Ann Rev Clin Psychol* 15: 399–423. https://doi.org/10.1146/annurev-clinpsy-050718-095557
23. Kendler KS, Kessler RC, Walters EE, MacLean C, Neale MC, Heath AC, et al. (2010) Stressful life events, genetic liability, and onset of an episode of major depression in women. *Focus* 8: 459–470. https://doi.org/10.1176/foc.8.3.foc459
24. Kandel DB, Davies M, Raveis VH, (1985) The stressfulness of daily social roles for women: Marital, occupational and household roles. *J Health Soc Behav* 1985: 64–78. https://doi.org/10.2307/2136727
25. Burt VK, Stein K, (2002) Epidemiology of depression throughout the female life cycle. *J Clin Psychiatry* 63: 9–15.
26. Symonds JE, Galton M, (2014) Moving to the next school at age 10–14 years: An international review of psychological development at school transition. *Rev Educ* 2: 1–27. https://doi.org/10.1002/rev3.3021
27. Nurmi JE, Salmela-Aro K, Goal construction, reconstruction and depressive symptoms in a life-span context: The transition from school to work. *J Pers* 70: 385–420. https://doi.org/10.1111/1467-6494.05009
28. Rosenthal T, Alter A, (2012) Occupational stress and hypertension. *J Am Soc Hypertens* 6: 2–22. https://doi.org/10.1016/j.jash.2011.09.002
29. Lewis SNC, Cooper CL, (2018) Stress in two-earner couples and stage in the life-cycle. *Routledge* 2018: 165–179. https://doi.org/10.4324/9781315196244-13