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Global Trends in the Incidence, Prevalence and Disability-Adjusted Life Years of Leprosy from 1990 to 2019: An Age-Period-Cohort Analysis Using the Global Burden of Disease Study 2019

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Background: Leprosy is a neglected tropical disease, with approximately 200,000 new cases reported worldwide every year. Although there are numerous studies on the epidemiology of leprosy, the age, period, and cohort effects remain poorly understood.
Objective: We present an overview of trends in leprosy incidence, prevalence and disability-adjusted life years worldwide from 1990 to 2019 and associations with age, period, and birth cohort. Data for analysis were obtained from the Global Burden of Disease Study 2019.
Methods: We described incident case, prevalent case, age-standardised incidence, prevalence and disability-adjusted life years rates of leprosy from 1990 to 2019. Subsequently, we calculated overall annual percentage changes, annual percentage changes, and the relative risks of period and cohort using an age-period-cohort model.
Results: From 1990 to 2019, the global age-standardized incidence rate of leprosy decreased from 1.48 per 100,000 to 0.65 per 100,000. Additionally, countries with low Socio-Demographic Index (*SDI*) demonstrated higher age-standardised incidence, prevalence and disability-adjusted life years rate. The age-standardised incidence, prevalence and disability-adjusted life years rate were significantly higher in males compared to females. Furthermore, the impact of age on leprosy increased with age, peaking at 25–35 years, with the highest prevalence rates observed in the 35–40 age group. Notably, the peak age of leprosy onset increases with SDI. Both the period and cohort effects on leprosy incidence and prevalence showed decreasing trend in middle SDI, low-middle SDI and low SDI countries in recent 30 years and birth cohort later than 1905. However, unfavorable period and cohort effects were noted in high SDI regions.
Conclusion: Leprosy incidence, prevalence and disability-adjusted life years have significantly decreased globally, but remain high in areas with lower SDI. Developing regions should increase public awareness of leprosy risk factors, develop effective control policies to better manage and prevent the disease.
Keywords: leprosy, epidemiology, age-period-cohort analysis, global burden of disease study

Introduction

Leprosy is a chronic infectious disease caused by the *Mycobacterium leprae*, slow-growing intracellular parasite with a tropism for macrophages and Schwann cells, primarily affecting the skin and peripheral nervous system.[1–3] This disease is characterized by difficulty in recognizing early signs and symptoms, a long incubation period, and difficulty in determining the time of onset.[4] Leprosy is often accompanied by neuritis and leprosy reactions, and in severe cases, it can lead to deterformation and disability, so it poses a great threat to human health.[1] Additionally, the physical deformities caused by leprosy often lead to stigma, social prejudice and discrimination.

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Since the introduction of multi-drug therapy (*MDT*) in the early 1980s, the worldwide incidence of leprosy has dropped dramatically.[5] Despite significant reductions in incidence and prevalence due to the World Health Organization's control strategy, new cases continue to emerge. The WHO's latest global leprosy strategy is "Towards zero leprosy", with a long-term vision of zero infection and disease, zero disability, zero stigma and discrimination.[6] Globally, a total of 140594 new leprosy cases were reported in 2021, with Southeast Asia, the Americas, Africa, the Eastern Pacific, and the Western Mediterranean showing concentration. India remains the epicenter of global leprosy cases.[7,8] Leprosy is currently classified as a neglected tropical disease, and global elimination has been a longstanding goal. Therefore, it is crucial for ongoing efforts to monitor the global leprosy burden.

Epidemiological studies could help shed light on the burden of leprosy on human health from a macro perspective and provide basis for improving public health at the global, regional, and national level, allocating medical resources reasonably, and formulating health strategies. Despite the ongoing follow-up on the global and national leprosy burden, few studies have analyzed the leprosy trends at the global, regional, and country levels based on the Global Burden of Disease Study. Access to global data and comparisons between countries could significantly enhance our understanding of the complexities and trends of leprosy. Additionally, there is a lack of in-depth analyses on the effects of age, period, and birth cohort, as well as comparisons across multiple countries. Age-period-cohort *(APC*) analysis can illuminate how time and population dynamics influence the occurrence and spread of diseases. The strength of this analytical method lies in its capacity to assess the effects of various age groups, time periods, and birth cohorts concurrently, offering a deeper understanding of the evolving nature of diseases.[9,10] The availability of the Global Burden of Disease Study database provides researchers with the opportunity for thorough analysis and investigation.[11]

In the present study, we obtained data from the GBD 2019 to assess the time trends of leprosy incidence, prevalence and DALY globally over the past three decades. In addition to analyzing the change pattern of incident case, prevalent case, the age-standardized incidence rates (*ASIR*), age-standardized prevalence rates (*ASPR*) and age-standardised disability-adjusted life years (*DALY*) rate, we also evaluated how trends in leprosy incidence, prevalence and DALY differ based on age, period, and birth cohort effects at the global, regional levels.

Methods

Data Sources

We obtained data on the incidence, prevalence and DALY of leprosy from the Global Health Data Exchange GBD Results Tool (http://ghdx.healthdata.org/gbd-results-tool). The tool provides the most up-to-date estimation of the descriptive epidemiological data on a total of 369 diseases and 87 risk factors for 204 countries and territories within 21 GBD regions from 1990 to 2019. Data sources in the estimation process for GBD estimates include population censuses, household surveys, civil registration and vital statistics, disease registers, health service use, air pollution monitoring, disease notifications, and other sources.[12] All disease estimates of GBD contain 95% uncertainty intervals (UIs), and countries with fewer or no data sources for the 25th and 975th ordinal values based on a 1000 posterior distribution generally have a higher 95% UI, suggesting greater inaccuracy in disease estimates.[12]

This analysis used the Socio-Demographic Index (SDI) for each country, a comprehensive indicator of a country's development status, which is derived from a comprehensive assessment of the overall fertility rate of women under 25 years of age, the average education level of women aged 15 and over, and per capita income. The SDI ranges from 0 to 1, with higher values for countries with higher socio-economic levels. Based on the 2019 SDI values, all countries are divided into five regions, namely, low (0–0.455), low-middle (0.456–0.608), middle (0.609–0.690), high-middle (0.691-–0.805), and high (0.806–1) SDI regions. By dividing countries into SDI quintiles, we can more clearly compare the differences in leprosy burden among different levels and explore the relevant factors, providing a basis for formulating targeted prevention and control strategies.[13] Furthermore, we choose the estimated annual percentage change (*EAPC*) in ASIR and ASPR to quantify the temporal trends of leprosy burden worldwide, from 1990 to 2019.[14,15]

Descriptive Analysis

Our study analyzed incident case, prevalent case, age-standardised incidence, prevalence and DALY rates of leprosy and their spatial and temporal trends from 1990 to 2019. This study reported on leprosy incidence, prevalence and DALY in different SDI regions in 2019 and provided a global view of leprosy incidence and prevalence, comparing differences in leprosy incidence and prevalence between countries and regions. We plotted leprosy incidence, prevalence and DALY from 1990 to 2019 to compare across years.

Age-Period-Cohort Analysis

The age-period-cohort model is a commonly used statistical model for extracting information hidden in disease morbidity and mortality. This model is widely used in the field of epidemiology, and the model requires data to conform to the Poisson distribution.[16] The model decomposes the research indicators into three dimensions: age, period, and birth cohort, and analyzes the effects of age, period and birth cohort on disease incidence and mortality. Age effects reflect changes in age, including the impact of population ageing on morbidity or mortality. Period effect refers to the impact of changes in certain objective factors, such as disease screening methods, treatments, and interventions, on morbidity or mortality over a period. Cohort effect refers to the effect of different levels of exposure to disease risk factors on morbidity or mortality in different birth cohorts. Therefore, to better understand the long-term incidence trend of leprosy and explain its potential causes, the study used the *APC* model to analyze the incidence, prevalence and DALY trend of leprosy from 1990 to 2019, and explored the effects of age, period, and cohort on the incidence, prevalence and DALY of leprosy, to provide a basis for leprosy prevention and control.

The APC model was used to decompose the research indicators into three dimensions: age, period, and birth cohort, and the impact of these dimensions on incidence and prevalence was analyzed.[17] Due to the lack of leprosy data under 5 years old, 5−94 years old were selected as the research subjects in this study. Therefore, we divide the population aged 5–94 into 18 age groups (5–9, 10–14. 90–94), the data were arranged according to the five consecutive years from 1990–1994 to 2015–2019, divided into 6 period groups, and the reference period was 2000–2004. An individual's birth cohort is calculated using the time of death and individual age at death (ie, birth cohort = period-age). As a result, 23 consecutive birth cohorts were also created, including those cohorts between 1900–1994 and 2010–2014, with cohort between 1955 and 1959 as reference groups.

To avoid possible non-identification problems due to the linear relationship between age, period, and cohort, we used the classical intrinsic estimator (*IE*) proposed by Yang et al to estimate the effect coefficients for age, period, and cohort,[18,19] and to estimate the ratio (*RR*) of leprosy incidence and prevalence in different periods and birth cohorts relative to the reference group. When the RR value is greater than 1, it indicates that this factor has the effect of increasing the risk of leprosy. When the RR value is less than 1, it indicates that this factor has the effect of reducing the risk of leprosy. To test the significance of the estimated parameters, Wald's chi-square test was used, and the p-value less than 0.05 was statistically significant. APC-IE analysis was performed through the R 4.3.1 software.

Results

Global, Regional, and National Incidence, Prevalence and DALY in Leprosy in 2019

In 2019, globally, the total number of leprosy incidence cases decreased from 73,078.12 (95% UI 64,129.85–85,174.30) to 52,714.94 (95% UI 46,035.07–61,339.42) compared to 1990. The age-standardised incidence rate (*ASIR*) of leprosy followed a similar declining trend, dropping from 1.48 per 100,000 (95% UI 1.30–1.73) to 0.65 per 100,000 (95% UI 0.57–0.75). Similarly, the total number of prevalent leprosy cases and the age-standardised prevalence rates (*ASPR*) also decreased. In 2019, the number of prevalent leprosy cases decreased from 793.96 thousand (95% UI 664.68–933.34) to 527.89 thousand (95% UI 449.95–619.99) compared to 1990. The age-standardised prevalence rate of leprosy decreased from 17.00 per 100,000 (95% UI 14.35–19.92) to 6.43 per 100,000 (95%UI 5.47–7.55). The age-standardised DALY rate decreased from 0.58 per 100,000 (95% UI 0.38–0.85) to 0.27 (95% UI 0.18–0.41) per 100,000 compared to 1990. Additionally, the ASIR, ASPR and age-standardised DALY rate in male were significantly higher than in females, almost twice as high as in females (Figure 1 and Table 1).

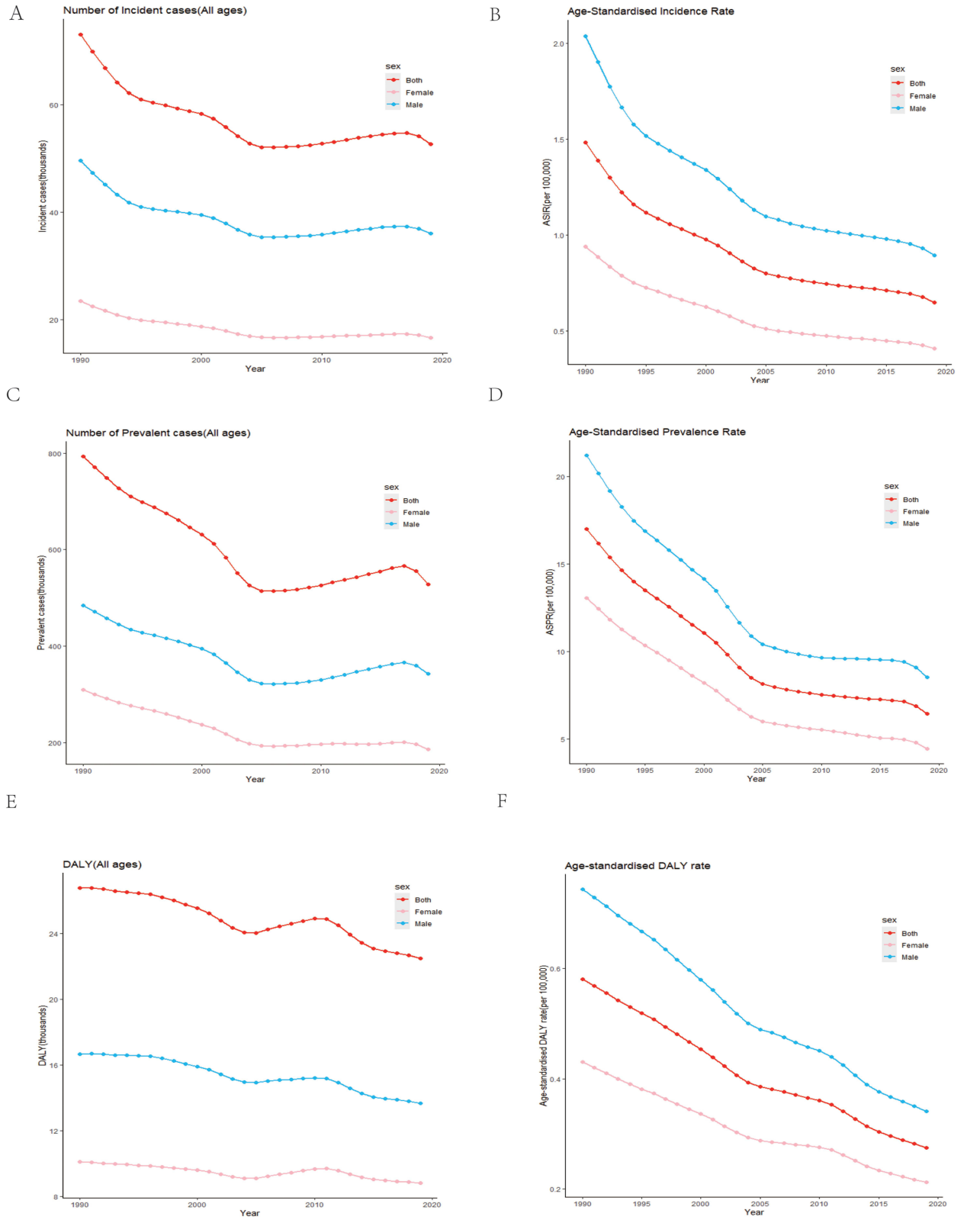

Figure 1 Global trend in incident case (**A**), ASIR (**B**), prevalent case (**C**), ASPR (**D**), DALY (**E**), age-standardised DALY rate (**F**) of leprosy from 1990 to 2019.

Table 1 The Age-Standardized Incidence, Prevalence, and DALY Rate for Leprosy in 1990 and 2019 and the Percentage Changes from 1990 to 2019

Location	1990			2019			Percentage Change 1990 to 2019		
	ASIR per 100,000 (95% UI)	ASPR per 100,000 (95% UI)	Age-Standardized DALY rate No. × 103 (95% UI)	ASIR per 100,000 (95%UI)	ASPR per 100,000 (95% UI)	Age-Standardized DALY rate No. × 103 (95% UI)	ASIR (95% UI)	ASPR (95% UI)	Age-Standardized DALY rate (95% UI)
Both	1.48 (1.3–1.73)	17 (14.35–19.92)	0.58 (0.38–0.85)	0.65 (0.57–0.75)	6.43 (5.47–7.55)	0.27 (0.18–0.41)	−0.56% (−0.58–0.55)	−0.62% (−0.64–0.59)	−0.56% (−0.58- −0.55)
Female	0.94 (0.81–1.09)	13.07 (10.91–15.38)	0.43 (0.28–0.63)	0.41 (0.35–0.48)	4.43 (3.74–5.23)	0.21 (0.14–0.31)	−0.57% (−0.59–0.55)	−0.66% (−0.68–0.63)	−0.55% (−0.57- −0.53)
Male	2.04 (1.76–2.39)	21.22 (18.02–24.77)	0.74 (0.49–1.10)	0.89 (0.77–1.05)	8.52 (7.3–9.99)	0.34 (0.22–0.50)	−0.56% (−0.58–0.55)	−0.6% (−0.62–0.57)	−0.56% (−0.57- −0.55)
SDI									
High	0 (0–0.01)	0.05 (0.04–0.06)	0.01 (0–0.01)	0.01 (0.01–0.01)	0.08 (0.07–0.1)	0.01 (0–0.01)	1.06% (0.92–1.27)	0.62% (0.54–0.71)	−0.43% (−0.48–0.38)
High middle	0.4 (0.34–0.49)	1.92 (1.66–2.22)	0.05 (0.03–0.08)	0.32 (0.27–0.38)	1.85 (1.59–2.15)	0.03 (0.02–0.05)	−0.22% (−0.25–0.2)	−0.04% (−0.07–0)	−0.39% (−0.43–0.34)
Middle	0.82 (0.69–1)	5.89 (5.07–6.83)	0.49 (0.32–0.71)	0.49 (0.42–0.59)	3.81 (3.26–4.46)	0.28 (0.18–0.41)	−0.41% (−0.43–0.39)	−0.35% (−0.37–0.33)	−0.46% (−0.48–0.44)
Low middle	4.23 (3.7–4.93)	57.52 (48.29–67.41)	1.65 (1.08–2.41)	1.27 (1.11–1.47)	14.41 (12.3–16.9)	0.61 (0.40–0.90)	−0.7% (−0.72–0.69)	−0.75% (−0.77–0.73)	−0.67% (−0.69–0.65)
Low	5.03 (4.51–5.65)	72.5 (60.52–85.8)	2.24 (1.48–3.25)	1.6 (1.43–1.81)	24.11 (20.42–28.48)	0.73 (0.49–1.07)	−0.7% (−0.71–0.68)	−0.67% (−0.69–0.64)	−0.71% (−0.73–0.69)
GBD region									
Andean Latin America	0.3 (0.27–0.34)	4.02 (3.35–4.69)	4.02 (3.35–4.69)	0.1 (0.09–0.11)	1.32 (1.1–1.57)	0.04 (0.02–0.06)	−0.67% (−0.69–0.65)	−0.67% (−0.7--0.64)	−0.81% (−0.83–0.79)
Australasia	0 (0–0)	0.01 (0.01–0.02)	0.01 (0.01–0.02)	0 (0–0)	0.01 (0.01–0.02)	0 (0–0)	−0.14% (−0.19–0.07)	−0.15% (−0.23–0.07)	−0.24% (−0.43–0.03)
Caribbean	0.53 (0.47–0.59)	6.21 (5.16–7.42)	6.21 (5.16–7.42)	0.36 (0.33–0.4)	4.96 (4.16–5.86)	0.16 (0.10–0.24)	−0.31% (−0.35–0.27)	−0.2% (−0.26–0.13)	−0.60% (−0.64–0.56)
Central Asia	1.23 (0.98–1.55)	3.08 (2.45–3.86)	3.08 (2.45–3.86)	0.77 (0.62–0.97)	1.94 (1.51–2.43)	0.63 (0.40–0.92)	−0.37% (−0.41–0.32)	−0.37% (−0.42–0.32)	−0.38% (−0.43–0.34)
Central Europe	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0% (0–0)	0% (0–0)	0% (0–0)
Central Latin America	0.25 (0.22–0.28)	2.63 (2.21–3.1)	0.21 (0.13–0.31)	0.13 (0.12–0.14)	1.31 (1.1–1.54)	0.08 (0.05–0.12)	−0.49% (−0.5--0.47)	−0.5% (−0.53–0.48)	−0.63% (−0.67–0.60)
Central Sub-Saharan Africa	4.59 (4.16–5.01)	31.87 (27.57–36.95)	3.40 (2.22–4.94)	1.97 (1.76–2.21)	33.6 (27.93–39.83)	0.72 (0.46–1.06)	−0.57% (−0.61–0.53)	0.05% (−0.02–0.13)	−0.82% (−0.84–0.78)
East Asia	0.08 (0.07–0.09)	1.45 (1.2–1.74)	0.08 (0.05–0.13)	0.04 (0.03–0.04)	0.65 (0.53–0.78)	0.02 (0.01–0.04)	−0.53% (−0.56–0.5)	−0.55% (−0.58–0.52)	−0.73% (−0.76–0.71)

(*Continued*)

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Table 1 (Continued).

Location	1990			2019			Percentage Change 1990 to 2019		
	ASIR per 100,000 (95% UI)	ASPR per 100,000 (95% UI)	Age-Standardized DALY rate No. × 103 (95% UI)	ASIR per 100,000 (95%UI)	ASPR per 100,000 (95% UI)	Age-Standardized DALY rate No. × 103 (95% UI)	ASIR (95% UI)	ASPR (95% UI)	Age-Standardized DALY rate (95% UI)
Eastern Europe	0 (0–0)	0 (0–0)	0 (0–0	0 (0–0)	0 (0–0)	0 (0–0)	0% (0–0)	0% (0–0)	0% (0–0)
Eastern Sub-Saharan Africa	3.02 (2.7–3.39)	37.73 (31.95–44.32)	1.87 (1.22–2.68)	1.19 (1.06–1.32)	16.62 (14.09–19.54)	0.66 (0.43–0.95)	−0.61% (−0.63–0.59)	−0.56% (−0.58–0.54)	−0.69% (−0.72- −0.66)
Location	**2010**			**2019**			**Percentage change 1990 to 2019**		
	ASIR per 100,000 (95% UI)	**ASPR per 100,000 (95% UI)**	**Age-Standardized DALY rate No. × 10–5 (95% UI)**	**ASIR per 100,000 (95% UI)**	**ASPR per 100,000 (95% UI)**	**Age-Standardized DALY rate No. ×10–5 (95% UI)**	**ASIR (95% UI)**	**ASPR (95% UI)**	**Age-Standardized DALY rate (95% UI)**
High-income Asia Pacific	0.01 (0.01–0.01)	0.12 (0.09–0.15)	0.02 (0.01–0.03)	0.01 (0.01–0.01)	0.11 (0.09–0.14)	0.01 (0–0.01)	−0.13% (−0.18–0.07)	−0.09% (−0.16–0)	−0.54% (−0.60- −0.47)
High-income North America	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0% (0–0)	0% (0–0)	0% (0–0)
North Africa and Middle East	0.27 (0.24–0.3)	3.6 (2.95–4.36)	0.15 (0.09–0.22)	0.13 (0.11–0.15)	1.84 (1.54–2.19)	0.04 (0.03–0.07)	−0.52% (−0.53–0.5)	−0.49% (−0.51–0.47)	−0.68% (−0.70- −0.65)
Oceania	2.76 (2.47–3.09)	37 (30.63–44.92)	1.54 (1.00–2.22)	2.18 (1.98–2.41)	32.37 (26.91–38.62)	0.76 (0.50–1.13)	−0.21% (−0.25–0.16)	−0.13% (−0.19–0.04)	−0.54% (−0.60- −0.47)
South Asia	5.86 (5.1–6.86)	79.97 (67.04–94.06)	2.07 (1.36–3.03)	1.57 (1.36–1.85)	18.08 (15.46–21.21)	0.72 (0.04–1.05)	−0.73% (−0.75–0.72)	−0.77% (−0.79–0.75)	−0.69% (−0.71–0.67)
Southeast Asia	1.43 (1.26–1.65)	13.33 (11.35–15.65)	1.94 (1.28–2.85)	0.81 (0.7–0.96)	6.06 (5.2–7.04)	0.41 (0.27–0.61)	−0.43% (−0.45–0.41)	−0.55% (−0.56–0.53)	−0.55% (−0.58- −0.52)
Southern Latin America	0.17 (0.15–0.19)	0.93 (0.8–1.09)	0.07 (0.04–0.11)	0.1 (0.09–0.11)	0.71 (0.6–0.82)	0.04 (0.02–0.06)	−0.4% (−0.45–0.35)	−0.24% (−0.29–0.2)	−0.48% (−0.52- −0.45)
Southern Sub-Saharan Africa	0.08 (0.07–0.1)	1.72 (1.41–2.08)	0.11 (0.07–0.17)	0.08 (0.07–0.09)	1.73 (1.41–2.11)	0.07 (0.04–0.10)	−0.08% (−0.13–0.02)	0% (−0.07–0.08)	−0.44% (−0.46- −0.41)
Tropical Latin America	4.71 (3.87–5.72)	25.92 (22.29–30.14)	1.85 (1.19–2.68)	3.43 (2.85–4.15)	22.04 (18.87–25.83)	1.37 (0.91–2.00)	−0.27% (−0.29–0.25)	−0.15% (−0.17–0.13)	−0.27% (−0.31–0.22)
Western Europe	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0% (0–0)	0% (0–0)	0% (0–0)
Western Sub-Saharan Africa	1.57 (1.42–1.75)	13.38 (11.23–15.78)	1.11 (0.73–1.64)	0.94 (0.84–1.06)	14.02 (11.68–16.7)	0.45 (0.29–0.66)	−0.4% (−0.43–0.37)	0.05% (−0.01–0.1)	−0.64% (−0.65- −0.62)

Next, we conducted a regional analysis of ASIR, ASPR and age-standardised DALY rate of leprosy based on SDI and 21 regions. In comparison to 1990, by 2019, High SDI, High-middle SDI, and Middle SDI countries exhibited a downward trend in ASIR, ASPR and age-standardised DALY rate, while other SDI countries did not show a clear trend. The ASIR, ASPR and age-standardised DALY rate of leprosy were highest in low SDI countries, with rates of 1.6 per 100,000, 24.11 per 100,000 and 0.73 per 100,000, respectively. Among the 21 regions in the GBD 2019, Tropical Latin America, Oceania, Central Sub-Saharan Africa, and South Asia had the highest ASIRs, ASPRs and age-standardised DALY rates (Figure 2 and Table 1).

In terms of countries and territories, the ASIR and ASPR of leprosy varied widely between different countries and territories in 2019. In 1990, areas with high ASIRs of leprosy included Micronesia, Kiribati, Marshall Islands, Bhutan, Nepal, and Mozambique, all exceeding 10.0 per 100,000. However, by 2019, only Micronesia, Kiribati, and Marshall Islands retained ASIRs exceeding 10.0 per 100,000, with decreasing ASIRs observed in most countries and territories over the three decades. The leprosy ASPR declined in almost all regions, with a decline of over 50% in the vast majority of Low-SDI and Low-middle SDI countries and territories. In 1990, Bangladesh, Bhutan, Equatorial Guinea, Kiribati, Micronesia, Mozambique, Nepal, and Timor-Leste recorded ASPRs higher than 100 per 100,000. By 2019, only Kiribati maintained an ASPR higher than 100 per 100,000, with Bangladesh, Bhutan, and Equatorial Guinea seeing drops to less than 1 per 10,000 people. Few countries and regions experienced an increase in leprosy ASPRs. For instance, the Central African Republic witnessed an increase from 62.84 per 100,000 to 169.65 per 100,000 (Figures 3 and 4).

Spatial and Temporal Trends of Leprosy Burden from 1990 to 2019

Furthermore, the annual percentage change in ASIR, ASPR and age-standardised DALY rate from 1990 to 2019 was estimated. At the global level, the annual percentage change of ASIR was −0.56% (95% CI: −0.58%, -0.55%) during the period from 1990 to 2019, and the annual percentage change of ASPR from 1990 to 2019 decreased by −0.62% (95% UI: from −0.64% to −0.59%). In terms of SDI level, the annual percentage change in ASIR and ASPR increased slightly in the high SDI region but the annual percentage change in ASIR and ASPR in the other four SDI regions and the annual percentage change in age-standardised DALY rate in five four SDI regions were on the decrease. As for the analysis of leprosy according 21 territories, the annual percentage change in the age-standardised incidence rates in Andean Latin America (−0.67% [95% UI −0.69% to −0.65%]), Central Sub-Saharan Africa (−0.57% [95% UI −0.61% to −0.53%]), Eastern Sub-Saharan Africa (−0.61% [95% UI −0.63% to −0.59%]) and South Asia (−0.73% [95% UI −0.75% to −0.72%]) decreased significantly from 1990 to 2019. However, the percentage change incidence kept steady in the following four territories such as Central Europe (0% [95% UI 0% to 0%]), Eastern Europe (0% [95% UI 0% to 0%]), Western Europe (0% [95% UI 0% to 0%]) and High-income North America (0% [95% UI 0% to 0%]). The top three statistically significant decreases in age-standardised prevalence rates were observed in South Asia (−0.77% [95% UI −0.79% to −0.75%]), Andean Latin America (−0.67% [95% UI −0.70% to −0.64%]), and Eastern Sub-Saharan Africa (−0.56% [95% UI −0.58% to −0.54%]). The most significant decline in the age-standardised DALY rate is in Andean Latin America, Central Sub-Saharan Africa, and East Asia. (Table 1)

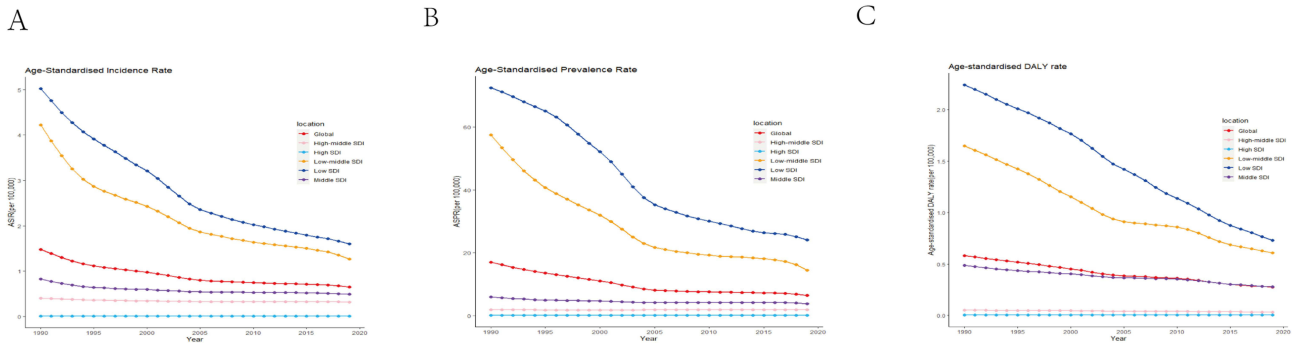

Figure 2 Global age-standardised incidence rate (**A**), age-standardised prevalence rate (**B**), age-standardised DALY rate (**C**) of leprosy by SDI regions from 1990 to 2019.

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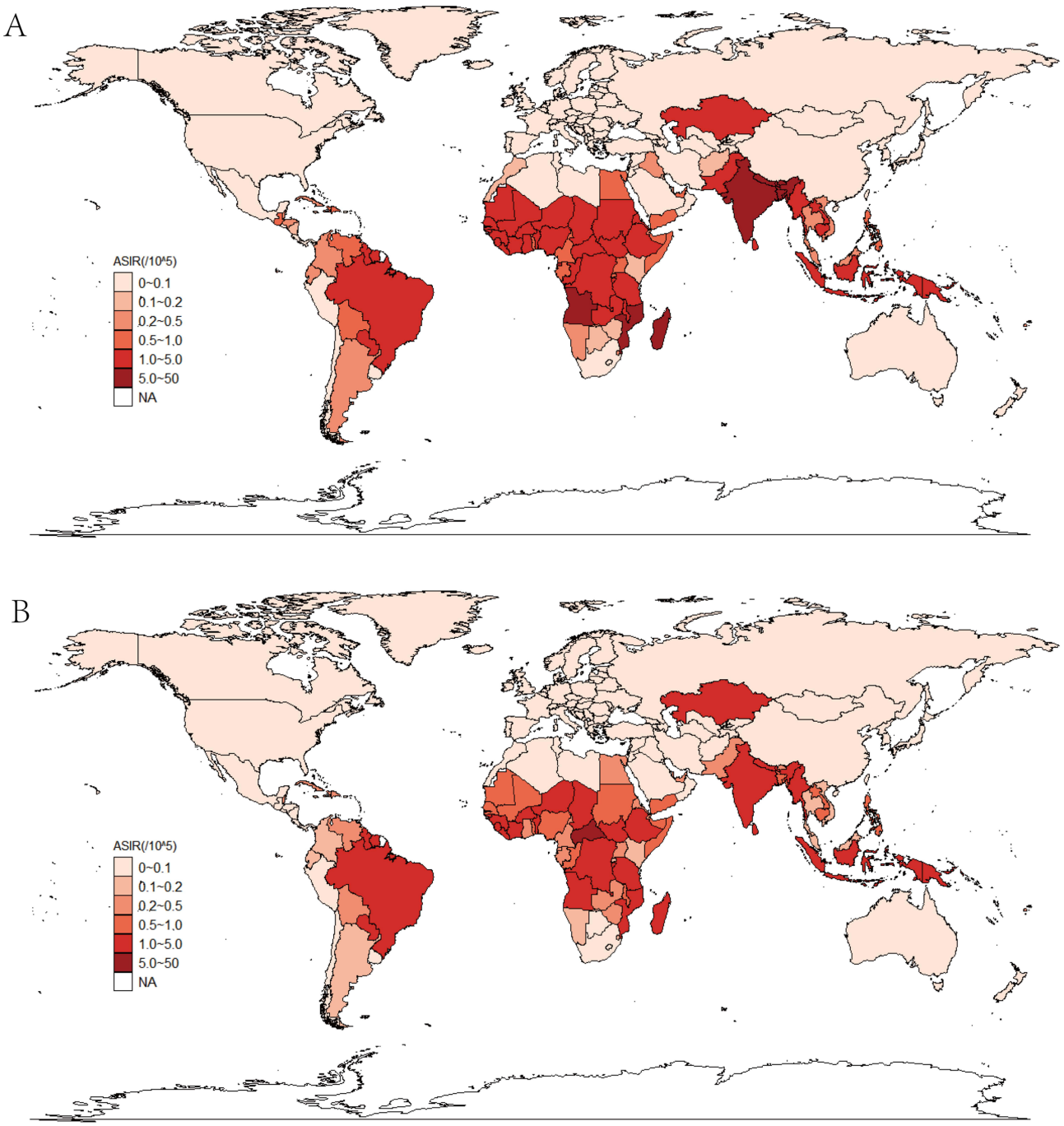

Figure 3 Age-standardised incidence rates of leprosy in 1990 (**A**) and 2019 (**B**) in 204 countries and territories.

Descriptive Analysis of Leprosy Incidence by Age, Period, and Birth Cohort Groups

Figure 5 illustrated global trends in leprosy incidence by age, period, and birth cohort group. The overall trend of leprosy incidence shows an initial increase followed by a decrease with age within each period. Leprosy incidence was lowest in the 5–9 age group and highest in the 45–69 age group. In most age groups, the incidence of leprosy decreased over time, with the most significant decrease in the middle and youth age groups. Additionally, there was decreasing trend in leprosy incidence across birth cohorts, indicating a relatively low risk of leprosy incidence in the most recent birth cohort.

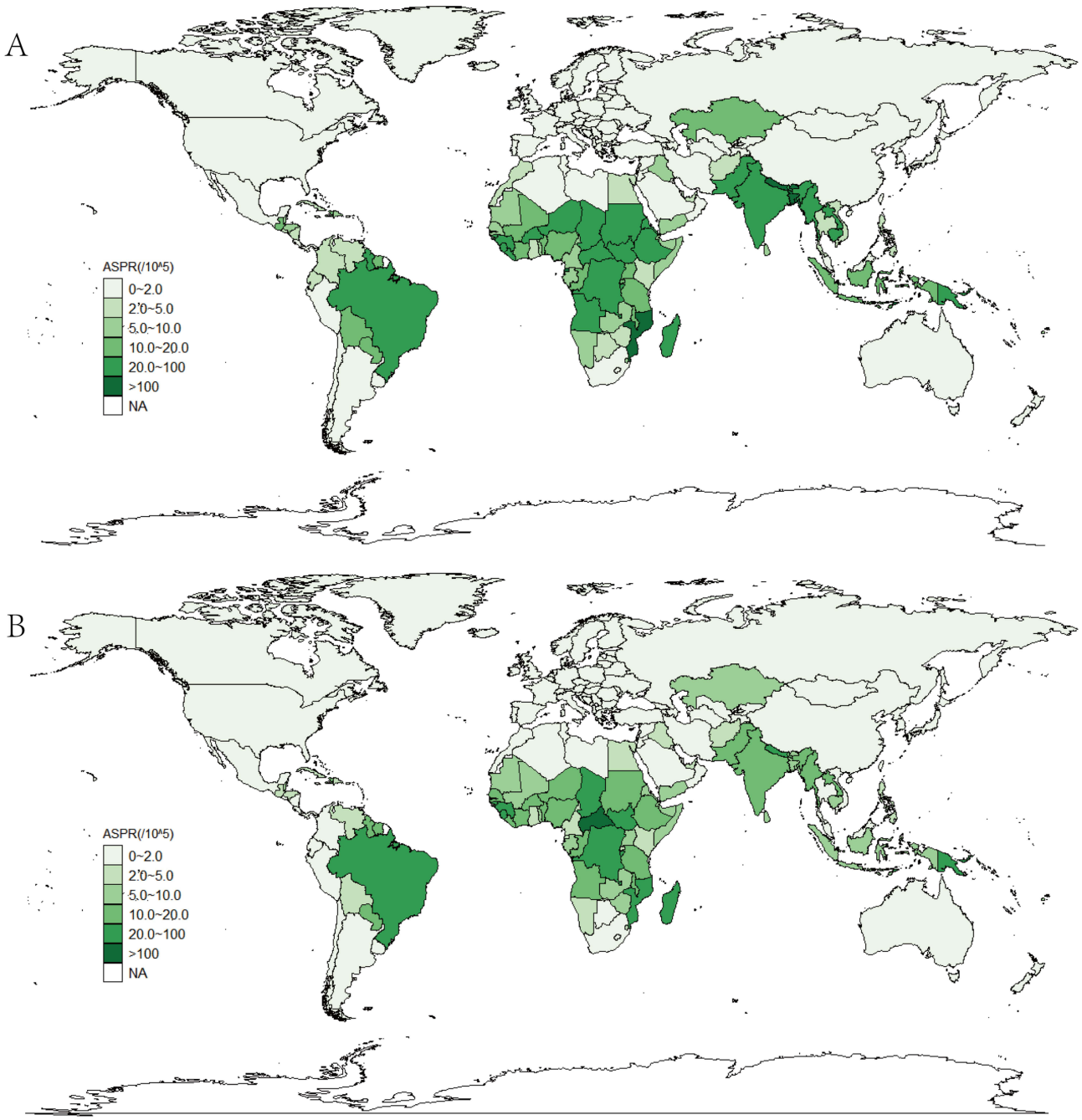

Figure 4 Age-standardised prevalence rates of leprosy in 1990 (**A**) and 2019 (**B**) in 204 countries and territories.

Age-Period-Cohort Effect Analysis on Leprosy in the Global Level and the Five SDI Regions

After adjusting for period and birth cohort effects, the age pattern of leprosy incidence, prevalence and DALY was consistent across the five SDI regions and globally. Incidence, prevalence and DALY initially increased with age, peaking in middle age, then declined. Notably, low and low-middle SDI regions saw the sharpest increases, while middle and high-middle SDI regions experienced more gradual rises, and high SDI regions remained stable. The peak age of leprosy onset shifted from low to high SDI countries, with prevalence and DALY peaking later than incidence. The incidence of

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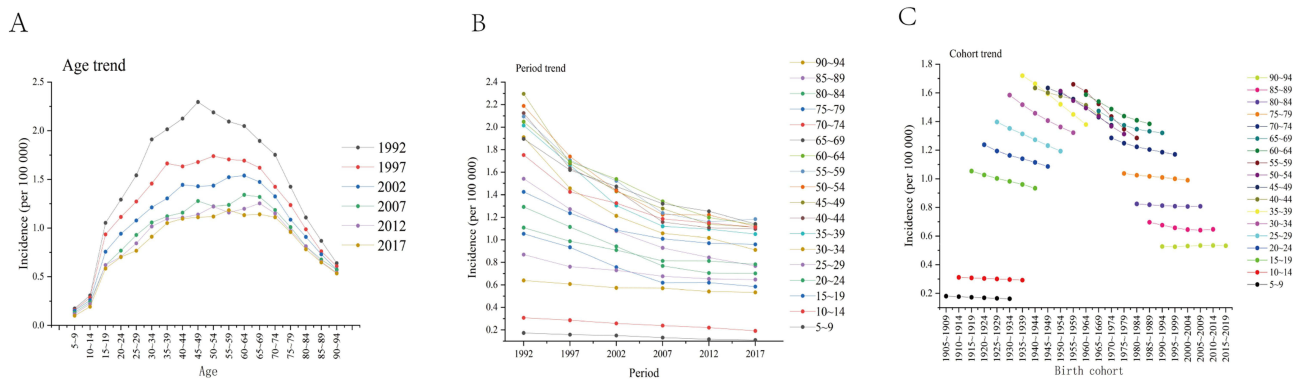

Figure 5 Global trends in leprosy incidence. (**A**) Global trends in leprosy incidence by age. (**B**) Global trends in leprosy incidence by period. (**C**) Global trends in leprosy incidence by birth cohort.

children aged 5–9 and 10–15 years in low and low-middle SDI regions is significantly higher than the global level (Figure 6A, D and G).

Period effects on incidence, prevalence and DALY varied significantly across SDI regions, except for high SDI countries. Middle, low-middle, and low SDI countries showed declining trends, while high-middle SDI regions experienced increasing prevalence effects in the last 15 years. Conversely, high SDI countries saw rising risks over the past three decades in incidence and prevalence. Relative risks (RRs) of incidence, prevalence and DALY from 2015–2019 compared to 2000–2004 ranged from 0.62 (95% UI: 0.61 to 0.64) to 1.54 (95% UI: 1.05 to 2.26) for incidence, from 0.92 (95% UI: 0.89 to 0.94) to 1.35 (95% UI: 1.21 to 1.51) for prevalence, from 0.49 (95% UI: 0.47 to 0.51) to 0.87 (95% UI: 0.57 to 1.31) for DALY across the five SDI regions (Figure 6B, E and H).

Similarly, cohort effects differed significantly across SDI regions, except incidence and prevalence for high SDI countries. Declining trends were observed in middle and low-middle SDI countries, starting with cohorts born after 1905, contrasting with a less significant decrease in high-middle SDI regions. Relative cohort risks of incidence rate decreased notably in low SDI countries. Prevalence trends varied, with increasing prevalence observed before 1990 in middle, low-middle, and low SDI countries. In high-middle SDI regions, prevalence showed a peak-and-decline pattern across cohorts. In high SDI regions, unfavorable cohort effects on incidence and prevalence were noted (albeit not statistically significant), however cohort effects on DALY maintained a sustained downward trend (Figure 6C, F and I).

Discussion

As a millennial disease, leprosy is widespread in at least 122 countries, and its continued endemicity is a public health and social issue of global concern.[20] Although the World Health Organization (WHO) declared leprosy eliminated in 2000 (defined as less than 1 case per 10,000 people), the global incidence of new cases has remained relatively stable over the past decade.[21] Our study also indicates that while the global incidence, prevalence and DALY of leprosy decreased from 1990 to 2019, the global leprosy prevalence rate stood at 6.43 cases per 100,000 in 2019. Over the past three decades, all countries have achieved elimination as a public health problem, thanks to the World Health Organization's effective control and eradication strategy.[22] However, global eradication of leprosy remains a challenge of drug resistance, relapse of leprosy and treatment failure.[23–25]

The incidence, prevalence and DALY in males were significantly higher than in females. A meta-analysis revealed a notably lower proportion of leprosy cases in women, with a pooled proportion of 37%.[3] Another study showed that globally, about 35–37% of all new reported cases of leprosy were in women, with few cases in women in some countries, possibly due to underdiagnosis in women.[26] This gender gap may be attributed to men having better healthcare access and being more socially active, potentially leading to increased vector exposure.[3,26] Despite significant progress globally in reducing the incidence, prevalence and DALY of leprosy, concerning trends persist in some regions.

Additionally, our study found that the age-standardised incidence, prevalence and DALY rate of leprosy decreased with increasing SDI, with the lowest rates observed in regions with high SDI. Previous studies utilized per capita

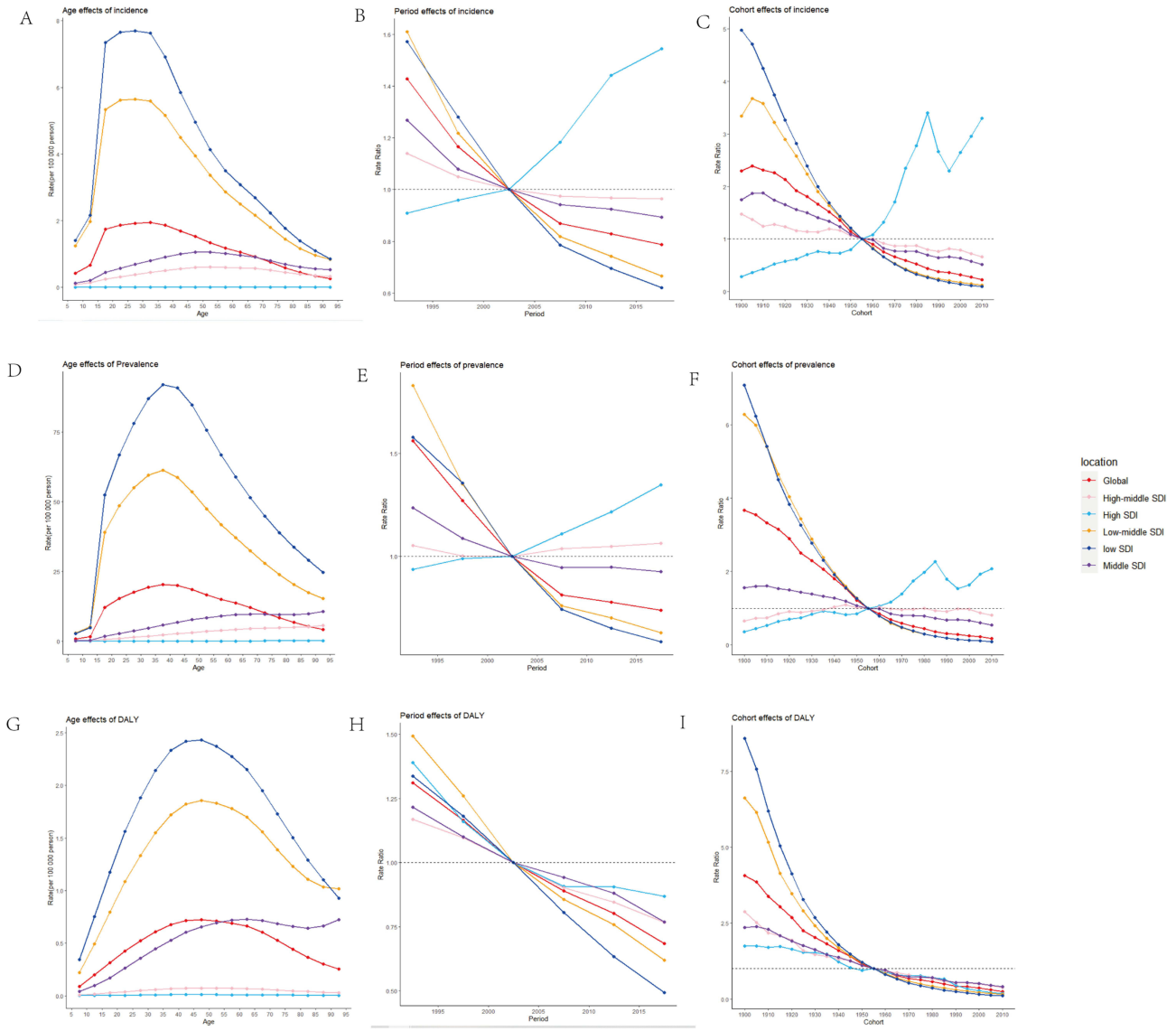

Figure 6 Estimates of age (**A, D, G**), period (**B, E, H**), and cohort (**C, F, I**) effects on the incidence, prevalence and DALY of leprosy in global and five-SDI quintiles from 1990 to 2019.

household income as a measure of socioeconomic status, demonstrating a correlation between poverty and leprosy risk.[27,28] Moreover, two studies from Brazil utilized the Gini Index to evaluate inequality[29] and the income ratio between the wealthiest and poorest 20%,[30] respectively, both shedding light on the correlation between leprosy and socio-economic disparities. Overall, these results indicate that leprosy risk is linked not only to low socioeconomic development but also to levels of inequality. Leprosy should be recognized as a poverty-related disease, and its prevention and treatment should be integrated into poverty alleviation programs. Furthermore, our study found that Tropical Latin America, Oceania, Central Sub-Saharan Africa, and South Asia had the highest ASIR in 2019. Previous study showed that the regional proportion of all new cases in 2019 was 71.3% in Southeast Asia, 14.9% in the Americas, 9.9% in Africa, 2.1% in the Eastern Mediterranean, and 1.9% in the Western Pacific,[31] consistent with our results. We also observed that leprosy's high incidence is primarily concentrated in tropical regions, suggesting a higher risk for individuals living in these areas. This is partly attributed to environmental factors such as soil, humidity, vegetation, and thermal-hydrologic climate, which can serve as sources of leprosy transmission.[32–35] Similar to our study, other authors have also noted a downward trend in the number of new leprosy cases in many countries, including India,

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Mexico, Japan, South Korea, and Saudi Arabia.[36–39] This decline may be due to access to health services, the provision of multi-agent chemotherapy for newly identified cases,[37] contact tracing and monoprophylaxis. Immediate treatment and the effectiveness of MDT upon diagnosis reduced the number of infections.

In terms of age, our study demonstrated that the highest rates on incidence, prevalence and DALY were found in the 25–35 age group, 35–40 age group and 40–45 age group, respectively. The Immunological effects of pregnancy in young adults lead to a higher incidence of leprosy in these age groups.[40] Given that these age groups typically comprise the economically active population, disabilities and incapacities resulting from leprosy can significantly impact both their work and social environments, leading to not only economic but also psychological losses for individuals and their communities. Furthermore, our research indicated that the peak age of leprosy onset increases with Socio-Demographic Index (*SDI*). This trend can be attributed to the decrease in leprosy incidence, resulting in new patients experiencing longer incubation periods, consequently leading to a higher age of onset.[41] Additionally, the prevalence of leprosy peaks later than the incidence rate, which aligns with the limited duration of active leprosy. Finally, the incidence of children under 15 years of age in low and low-middle SDI regions is significantly higher than the global level. The detection of new cases in children is a surrogate sign of sustained community transmission and implies active transmission.[42] A study of leprosy in children in Cuba showed that most children diagnosed with leprosy had a history of leprosy in their relatives.[42] Therefore, low SDI countries need to invest more in providing early diagnosis and early detection of leprosy cases for people at high risk of infection to prevent further household and community transmission, thereby reducing morbidity and disability rates in children.

Period effects often reflect the impact of social, economic, and medical factors on disease across all age groups. The RRs of the period on incidence, prevalence, and DALY of leprosy revealed that the risk of developing leprosy decreased in middle SDI, low-middle SDI, low SDI countries from 1990 to 2019. In contrast, RRs have increased in high-middle SDI countries over the past 15 years. Part of the reason for the downward trend may be that the introduction of multidrug therapy (*MDT*) reduces the burden of *Mycobacterium leprae* in the community, thereby reducing the spread of infection.[43] In 1981, a WHO study team recommended that patients with leprosy should be treated with a combination of three drugs (rifampicin, clofazimine and dapsone), with rifampicin, the most effective drug, as the backbone of the MDT.[44] It took about 15 years to achieve global coverage of all registered leprosy patients after the WHO called for universal MDT.[45,46] By 1991, the number of leprosy patients worldwide had decreased from 5.3 million in 1985 to 3.1 million.[47] The World Health Organization recommends a reduction in the treatment duration from 2 years to 1 year for multibacillary cases and from 1 year to six months for paucibacillary cases in 1997.[48] This change automatically reduces the leprosy prevalence in subsequent years since leprosy prevalence is based on the number of patients who are still receiving MDT. Another reason for the declining trend could be the increased steadily coverage of Bacillus Calmette-Guérin vaccination. There is substantial evidence that BCG case–control studies have shown that BCG is protective against leprosy, especially when repeated vaccinations, although the degree of this protection varies widely, from 20% to 80%.[49–51] In leprosy-endemic areas, increasing vaccination coverage and ensuring timely BCG vaccination in routine childhood immunization programs is expected to reduce the incidence of leprosy. Surprisingly, the period effects of incidence and prevalence have increased for high-middle SDI and middle SDI countries over the past 15 years. Over the years, some new cases have been reported in some European countries such as France, Spain and Italy, and the majority of cases are in migrants from other leprosy-endemic countries.[52–54] In the US state of Florida, the incidence of leprosy has increased since 2010. It is believed that human leprosy and exposure here are linked to environmental sources of the nine-banded armadillo and leprosy.[55] Therefore, leprosy eradication is still considered a challenging goal for low-middle and low-SDI countries with low leprosy risk.

Cohort effects on leprosy incidence, prevalence and DALY showed a decreasing trend from 1905 cohort to 2014 cohort in middle SDI, low-middle SDI, and low SDI countries. This trend probably arose because of educational improvements, increased access to sufficient food, and a reduction in overcrowding. Previous studies have shown that food shortages and food insecurity are positively associated with the occurrence of leprosy, and it is suggested that impaired host immune response to pathogenic bacteria due to inadequate nutrient intake may be responsible for the occurrence of leprosy.[56] Higher levels of education are associated with a reduced likelihood of developing leprosy,[57] as education often correlates with improved economic outcomes. In addition, it is found that crowded living conditions were significantly associated with a higher risk of leprosy.[58]

Our study has several advantages and limitations. This study is the first attempt, to our knowledge, to compare and analyze a composite estimate of leprosy incidence, prevalence and DALY by age, sex, global, regional, and national levels spanning from 1990 to 2019. We also utilize the APC model to assess the effects of age, period, and birth cohort on leprosy rates. However, it relies on cross-sectional data from the GBD study from 1990 to 2019, which was not a cohort study. Leprosy-related data are lacking in many countries, and estimates are mainly derived from predicted covariates and neighboring locations, and we are unable to obtain original data for more accurate analysis.[59] While our study covers a global scale, the findings of specific regions and countries may not be generalizable to others due to differences in socio-economic, environmental, and public health factors. Therefore, large-scale cohort studies are urgently needed to obtain better and more extensive raw data and address these limitations. During the Covid-19 pandemic, the detection of many cases was suspended or restricted, and the diagnosis of leprosy became difficult, resulting in a decrease in the incidence and prevalence of leprosy. A 2020 study in Brazil showed that the number of leprosy cases in Brazil decreased by 11,357 (41.4%) in 2020 compared to the average number of cases between 2015 and 2019.[60] However, this study was unable to study the incidence, prevalence and DALY during the Covid-19 pandemic.

Conclusion

Overall, from 1990 to 2019, the global incidence, prevalence and DALY of leprosy decreased significantly, and the incidence, prevalence and DALY were significantly higher in men than in women. The age-standardised incidence, prevalence and DALY rates of leprosy are higher in areas with lower SDI. The risk of morbidity is highest in people aged 25–35 years, the risk of prevalence is highest in people aged 35–40 years, and the highest DALY is in people aged 40–45 years. Surprisingly, unfavorable periods and cohort effects have been observed in high SDI regions. Our study shows that the age-standardised incidence, prevalence, and DALY rate of leprosy are inversely correlated with the Social Development Index and that the degree of poverty and inequality is associated with leprosy risk. The high incidence of leprosy is concentrated in the tropics, where soil, moisture, vegetation and hydrothermal climate may be sources of leprosy transmission. Migrants from other leprosy-endemic countries in the context of globalization and increased human exposure to the nine-banded armadillo carrying *Mycobacterium leprae* are important reasons for the negative trend in high-SDI areas. Therefore, in order to effectively prevent and manage leprosy, it is crucial to enhance public awareness of leprosy risk factors, conduct targeted leprosy screening among high-risk groups, vaccinate newborns with BCG in a timely manner, and increase investment in leprosy prevention and control in low-SDI areas.

Abbreviations

ASIR, the age-standardized incidence rates; ASPR, age-standardized prevalence rates; DALY, disability-adjusted life years; EAPC, estimated annual percentage change; SDI, Socio-Demographic Index; GBD, Global Burden of Disease Study; MDT, multidrug therapy; UIs, uncertainty intervals; APC, Age-period-cohort.

Ethics Approval and Informed Consent

This study is based on the GBD 2019 database, which does not contain identifiable personal information. Informed consent waiver was reviewed and approved by the University of Washington Institutional Review Board. In our research, we utilize publicly available data that is fully anonymized and does not involve any direct interaction with human subjects. According to item 1 and 2 of Article 32 of the Measures for Ethical Review of Life Science and Medical Research Involving Human Subjects dated February 18, 2023, China, research involving the use of publicly available data that cannot identify specific individuals or their privacy is exempt from ethical review by an Institutional Review Board (IRB) or ethics committee.

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Disclosure

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Lastória JC, Abreu MA. Leprosy: review of the epidemiological, clinical, and etiopathogenic aspects - part 1. *An Bras Dermatol*. 2014;89(2):205–218. doi:10.1590/abd1806-4841.20142450
2. Yu M, Sun P, Wang L, Wang H, Gu H, Chen X. Towards a leprosy-free country - China, 2011-2018. *China CDC Wkly*. 2020;2(4):50–53.
3. Marciano L, Belone AFF, Rosa PS, et al. Epidemiological and geographical characterization of leprosy in a Brazilian hyperendemic municipality. *Cad Saude Publica*. 2018;34(8):e00197216. doi:10.1590/0102-311X00197216
4. Britton WJ, Lockwood DN. Leprosy. *Lancet*. 2004;363(9416):1209–1219. doi:10.1016/S0140-6736(04)15952-7
5. Alrehaili J. Leprosy classification, clinical features, epidemiology, and host immunological responses: failure of eradication in 2023. *Cureus*. 2023;15(9):e44767. doi:10.7759/cureus.44767
6. World Health Organization. Towards zero leprosy: global leprosy (Hansen's disease) strategy 2021–2030. Geneva: World Health Organization, Available from: https://iris.who.int/handle/10665/340774. Accessed March 21, 2025.
7. Kundakci N, Erdem C. Leprosy: a great imitator. *Clin Dermatol*. 2019;37(3):200–212. doi:10.1016/j.clindermatol.2019.01.002
8. Barros I, Sousa C, Silva N, Mascarenhas MDM. Characterization of cases and epidemiological and operational indicators of leprosy: analysis of time series and spatial distribution, Piauí state, Brazil, 2007-2021. *Epidemiol Serv Saude*. 2024;33:e2023090. doi:10.1590/S2237-96222024v33e2023090.en
9. Bell A. Age period cohort analysis: a review of what we should and shouldn't do. *Ann Hum Biol*. 2020;47(2):208–217. doi:10.1080/03014460.2019.1707872
10. Rosenberg PS, Anderson WF. Age-period-cohort models in cancer surveillance research: ready for prime time? *Cancer Epidemiol Biomarkers Prev*. 2011;20(7):1263–1268. doi:10.1158/1055-9965.EPI-11-0421
11. Mckee M, Kimokoti R, Norheim OF, et al. Five insights from the global burden of disease study 2019. *Lancet*. 2020;396(10258):1135–1159. doi:10.1016/S0140-6736(20)31404-5
12. Vos T, Lim SS, Abbafati C, et al. Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the global burden of disease study 2019. *Lancet*. 2020;396(10258):1204–1222. doi:10.1016/S0140-6736(20)30925-9
13. Haile LM, Kamenov K, Briant PS. Hearing loss prevalence and years lived with disability, 1990-2019: findings from the global burden of disease study 2019. *Lancet*. 2021;397(10278):996–1009. doi:10.1016/S0140-6736(21)00516-X
14. Gao S, Yang WS, Bray F, et al. Declining rates of hepatocellular carcinoma in urban Shanghai: incidence trends in 1976-2005. *Eur J Epidemiol*. 2012;27(1):39–46. doi:10.1007/s10654-011-9636-8
15. Zhang W, Zeng W, Jiang A, et al. Global, regional and national incidence, mortality and disability-adjusted life-years of skin cancers and trend analysis from 1990 to 2019: an analysis of the global burden of disease study 2019. *Cancer Med*. 2021;10(14):4905–4922. doi:10.1002/cam4.4046
16. Yin M, Wang F, Zhang Y, et al. Analysis on incidence and mortality trends and age-period-cohort of breast cancer in Chinese women from 1990 to 2019. *Int J Environ Res Public Health*. 2023;20(1).
17. Wang N, Xu Z, Lui CW, Wang B, Hu W, Wu J. Age-period-cohort analysis of lung cancer mortality in China and Australia from 1990 to 2019. *Sci Rep*. 2022;12(1):8410. doi:10.1038/s41598-022-12483-z
18. Luo L. Assessing validity and application scope of the intrinsic estimator approach to the age-period-cohort problem. *Demography*. 2013;50(6):1945–1967. doi:10.1007/s13524-013-0243-z
19. Yang Y, Fu WJ, Land KC. A methodological comparison of age-period-cohort models: the intrinsic estimator and conventional generalized linear models. *Sociological Methodol*. 2004;34(1).
20. Abdela SG, Diro E, Zewdu FT, et al. Delayed diagnosis and ongoing transmission of leprosy in the post-elimination era in Boru Meda hospital, Ethiopia. *J Infect Dev Ctries*. 2020;14(6.1):10s–15s. doi:10.3855/jidc.11706
21. Maymone MBC, Laughter M, Venkatesh S, et al. Leprosy: clinical aspects and diagnostic techniques. *J Am Acad Dermatol*. 2020;83(1):1–14. doi:10.1016/j.jaad.2019.12.080
22. World Health Organization. Global leprosy strategy 2016-2020: accelerating towards a leprosy-free world - 2016 operational manual. Geneva: World Health Organization, 2016, Available from: https://iris.who.int/handle/10665/250119. Accessed March 21, 2025.
23. Nascimento A, Dos Santos DF, Antunes DE, et al. Leprosy relapse: a retrospective study on epidemiologic, clinical, and therapeutic aspects at a Brazilian referral center. *Int J Infect Dis*. 2022;118:44–51. doi:10.1016/j.ijid.2022.01.009
24. da Silva Rocha A, Cunha M, Diniz LM, et al. Drug and multidrug resistance among Mycobacterium leprae isolates from Brazilian relapsed leprosy patients. *J Clin Microbiol*. 2012;50(6):1912–1917. doi:10.1128/JCM.06561-11
25. de Carvalho Dornelas B, da Costa WVT, de Abreu JPF, et al. Role of histopathological, serological and molecular findings for the early diagnosis of treatment failure in leprosy. *BMC Infect Dis*. 2024;24(1):1085. doi:10.1186/s12879-024-09937-2
26. Yang J, Li X, Sun Y, et al. Global epidemiology of leprosy from 2010 to 2020: a systematic review and meta-analysis of the proportion of sex, type, grade 2 deformity and age. *Pathog Glob Health*. 2022;116(8):467–476. doi:10.1080/20477724.2022.2057722
27. Wagenaar I, van Muiden L, Alam K, et al. Diet-related risk factors for leprosy: a case-control study. *PLoS Negl Trop Dis*. 2015;9(5):e0003766. doi:10.1371/journal.pntd.0003766
28. Bhavsar BS, Mehta NR. An epidemiological study of leprosy through school survey in Surat District (South Gujarat). *Lepr India*. 1980;52(4):548–556.
29. Cabral-Miranda W, Chiaravalloti Neto F, Barrozo LV. Socio-economic and environmental effects influencing the development of leprosy in Bahia, north-eastern Brazil. *Trop Med Int Health*. 2014;19(12):1504–1514. doi:10.1111/tmi.12389
30. Freitas LR, Duarte EC, Garcia LP. Leprosy in Brazil and its association with characteristics of municipalities: ecological study, 2009–2011. *Trop Med Int Health*. 2014;19(10):1216–1225. doi:10.1111/tmi.12362

31. Li YY, Shakya S, Long H, Shen LF, Kuang YQ. Factors influencing leprosy incidence: a comprehensive analysis of observations in Wenshan of China, Nepal, and other global epidemic areas. *Front Public Health*. 2021;9:666307. doi:10.3389/fpubh.2021.666307
32. Truman R, Fine PE. 'Environmental' sources of mycobacterium leprae: issues and evidence. *Lepr Rev*. 2010;81(2):89–95.
33. Lavania M, Katoch K, Katoch VM, et al. Detection of viable Mycobacterium leprae in soil samples: insights into possible sources of transmission of leprosy. *Infect Genet Evol*. 2008;8(5):627–631. doi:10.1016/j.meegid.2008.05.007
34. Tadesse Argaw A, Shannon EJ, Assefa A, Mikru FS, Mariam BK, Malone JB. A geospatial risk assessment model for leprosy in Ethiopia based on environmental thermal-hydrological regime analysis. *Geospat Health*. 2006;1(1):105–113. doi:10.4081/gh.2006.285
35. Joshua V, Mehendale S, Gupte MD. Bayesian model, ecological factors & transmission of leprosy in an endemic area of South India. *Indian J Med Res*. 2016;143(1):104–106. doi:10.4103/0971-5916.178618
36. Sasidharanpillai S, Binitha MP, Riyaz N, et al. Childhood leprosy: a retrospective descriptive study from Government Medical College, Kozhikode, Kerala, India. *Lepr Rev*. 2014;85(2):100–110.
37. Assiri A, Yezli S, Tayeb T, Almasri M, Bamgboye AE, Memish ZA. Eradicating leprosy in Saudi Arabia: outcome of a ten-year surveillance (2003–2012). *Travel Med Infect Dis*. 2014;12(6 Pt B):771–777. doi:10.1016/j.tmaid.2014.10.002
38. Koba A, Ishii N, Mori S, Fine PE. The decline of leprosy in Japan: patterns and trends 1964-2008. *Lepr Rev*. 2009;80(4):432–440. doi:10.47276/lr.80.4.432
39. Larrea MR, Carreño MC, Fine PE. Patterns and trends of leprosy in Mexico: 1989-2009. *Lepr Rev*. 2012;83(2):184–194. doi:10.47276/lr.83.2.184
40. Lockwood DN, Sinha HH. Pregnancy and leprosy: a comprehensive literature review. *Int J Lepr Other Mycobact Dis*. 1999;67(1):6–12.
41. Irgens LM, Skjaerven R. Secular trends in age at onset, sex ratio, and type index in leprosy observed during declining incidence rates. *Am J Epidemiol*. 1985;122(4):695–705. doi:10.1093/oxfordjournals.aje.a114148
42. Rumbaut Castillo R, Hurtado Gascón LC, Ruiz-Fuentes JL, et al. Leprosy in children in Cuba: epidemiological and clinical description of 50 cases from 2012-2019. *PLoS Negl Trop Dis*. 2021;15(10):e0009910. doi:10.1371/journal.pntd.0009910
43. Smith CS, Aerts A, Saunderson P, Kawuma J, Kita E, Virmond M. Multidrug therapy for leprosy: a game changer on the path to elimination. *Lancet Infect Dis*. 2017;17(9):e293–e297. doi:10.1016/S1473-3099(17)30418-8
44. World Health Organization. *Chemotherapy of Leprosy for Control Programmes*. Geneva: World Health Organization; 1982. Available from: https://iris.who.int/handle/10665/38984. Accessed March 21, 2025.
45. World Health Organization. Multidrug therapy against leprosy: development and implementation over the past 25 years. Geneva: World Health Organization, 2004, Available from: https://www.who.int/publications/i/item/9241591765. Accessed March 21, 2025.
46. Lancet T. Making progress towards leprosy elimination. *Lancet*. 2006;367(9507):276. doi:10.1016/S0140-6736(06)68044-6
47. World Health Organization. Progress towards eliminating leprosy as a public health problem. Part II. *Wkly Epidemiol Rec*. 1994;69(21):153–157.
48. World Health Organization. Report on third meeting of the WHO technical advisory group on elimination of leprosy, Brasilia, 1 and 2 February 2002. Geneva: World Health Organization, 2002, Available from: https://iris.who.int/handle/10665/67302. Accessed March 21, 2025.
49. Lwin K, Sundaresan T, Gyi MM, et al. BCG vaccination of children against leprosy: fourteen-year findings of the trial in Burma. *Bull World Health Organ*. 1985;63(6):1069–1078.
50. Karonga Prevention Trial Group. Randomised controlled trial of single BCG, repeated BCG, or combined BCG and killed Mycobacterium leprae vaccine for prevention of leprosy and tuberculosis in Malawi. *Lancet*. 1996;348(9019):17–24. doi:10.1016/S0140-6736(96)02166-6
51. Cunha SS, Rodrigues LC, Pedrosa V, Dourado IM, Barreto ML, Pereira SM. Neonatal BCG protection against leprosy: a study in Manaus, Brazilian Amazon. *Lepr Rev*. 2004;75(4):357–366. doi:10.47276/lr.75.4.357
52. Bret S, Flageul B, Girault PY, Lightburne E, Morand JJ. Epidemiological survey of leprosy conducted in metropolitan France between 2009 and 2010. *Ann Dermatol Venereol*. 2013;140(5):347–352. doi:10.1016/j.annder.2013.02.019
53. Ramos JM, Romero D, Belinchón I. Epidemiology of leprosy in Spain: the role of the international migration. *PLoS Negl Trop Dis*. 2016;10(3):e0004321. doi:10.1371/journal.pntd.0004321
54. Massone C, Brunasso AM, Noto S, Campbell TM, Clapasson A, Nunzi E. Imported leprosy in Italy. *J Eur Acad Dermatol Venereol*. 2012;26(8):999–1006. doi:10.1111/j.1468-3083.2011.04201.x
55. Domozych R, Kim E, Hart S, Greenwald J. Increasing incidence of leprosy and transmission from armadillos in Central Florida: a case series. *JAAD Case Rep*. 2016;2(3):189–192. doi:10.1016/j.jdcr.2016.03.004
56. Kerr-Pontes LR, Barreto ML, Evangelista CM, Rodrigues LC, Heukelbach J, Feldmeier H. Socioeconomic, environmental, and behavioural risk factors for leprosy in North-east Brazil: results of a case-control study. *Int J Epidemiol*. 2006;35(4):994–1000. doi:10.1093/ije/dyl072
57. Cordeiro TL, Cipriani Frade MA. Leprosy: education as first priority. *J Neurosci Rural Pract*. 2014;5(Suppl 1):S3–4. doi:10.4103/0976-3147.145191
58. Bakker MI, Hatta M, Kwenang A, et al. Risk factors for developing leprosy--a population-based cohort study in Indonesia. *Lepr Rev*. 2006;77(1):48–61.
59. Ärnlöv J; GBD 2019 Demographics Collaborators. Global age-sex-specific fertility, mortality, healthy life expectancy (HALE), and population estimates in 204 countries and territories, 1950-2019: a comprehensive demographic analysis for the global burden of disease study 2019. *Lancet*. 2020;396(10258):1160–1203. doi:10.1016/S0140-6736(20)30977-6
60. da Paz WS, Souza MDR, Tavares DDS, et al. Impact of the COVID-19 pandemic on the diagnosis of leprosy in Brazil: an ecological and population-based study. *Lancet Reg Health Am*. 2022;9:100181. doi:10.1016/j.lana.2021.100181