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ORIGINAL RESEARCH

Global, Regional, and National Burden of Adolescent Polycystic Ovary Syndrome from 1990 to 2021, with Projections of Disease Burden to 2041: A Systematic Analysis Based on the Global Burden of Disease Study 2021

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Background: Polycystic ovary syndrome (PCOS) is a common endocrine and metabolic disorder affecting adolescent girls globally. Despite its prevalence, the global burden of adolescent PCOS has not been systematically assessed. This study aims to evaluate the worldwide impact of PCOS among adolescents from 1990 to 2021 and forecast its future trajectory using data from the Global Burden of Disease (GBD) Study 2021.

Methods: We analyzed trends in incidence, prevalence, and disability-adjusted life years (DALYs) associated with adolescent PCOS using GBD 2021 data. The analysis was stratified by age, socio-demographic index (SDI), and geographic region. Temporal trends were assessed using the estimated annual percentage change (EAPC). Health inequality analysis and frontier analysis were applied to examine disparities and identify potential for burden reduction. An autoregressive integrated moving average model was used to forecast the future burden of adolescent PCOS from 2022 to 2041.

Results: The global age-standardized incidence rate of adolescent PCOS increased from 268.64 per 100,000 in 1990 to 348.21 per 100,000 in 2021 (EAPC: 0.81%). The prevalence rate rose from 1176.61 per 100,000 to 1526.36 per 100,000 (EAPC: 0.89%), and the DALYs rate increased from 10.53 to 13.62 per 100,000 (EAPC: 0.88%). Health inequality analysis revealed a widening gap between high- and low-SDI regions, with a disproportionate concentration of burden in higher-SDI countries. Frontier analysis identified countries like Italy and Japan as having greater potential for burden reduction. Southeast Asia exhibited the most rapid growth, with EAPCs exceeding 2.4%—approximately three-fold higher than the global average.

Conclusion: The global burden of adolescent PCOS has steadily increased from 1990 to 2021, with significant regional disparities. The widening health inequality and rapid growth in Southeast Asia underscore the urgent need for targeted public health interventions. The projected rise in burden underscores the urgent need for targeted public health interventions, especially in regions with rapid increases in incidence and prevalence.

Plain Language Summary: PCOS represents one of the most common hormonal disorders affecting adolescent females, typically characterized by disrupted menstrual cycles, elevated androgen levels, and an increased risk of enduring reproductive and metabolic health issues. This study investigates the global epidemiological trends of PCOS in adolescents, with a particular focus on its increasing prevalence in Southeast Asia and low-income regions. The results reveal a marked increase in both the occurrence and overall burden of the disease over the last thirty years. By 2021, the worldwide age-standardized incidence rate had surpassed 348 cases per 100,000 adolescent females. The study further reveals a growing disparity in healthcare access, with low-income countries experiencing a more rapid escalation in PCOS burden, underscoring the need for improved diagnostic capacity and treatment infrastructure. Forecasts suggest that this upward trend will persist in the coming years, highlighting the urgent need for enhanced early detection, preventive strategies, and equitable healthcare interventions, particularly in high-risk and underserved populations.

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Introduction

Polycystic ovary syndrome (PCOS) is a widespread hormonal and metabolic condition that significantly influences the health of women during their reproductive years.[1] PCOS, characterized by chronic anovulation, hyperandrogenism, and polycystic ovarian morphology,[2] manifests through a spectrum of clinical features including menstrual irregularities, infertility, hirsutism, and metabolic disturbances such as obesity and insulin resistance.[3] It is the leading cause of anovulatory infertility and is frequently associated with menstrual irregularities (oligomenorrhea or amenorrhea), hirsutism, acne, alopecia, and central obesity, which can exacerbate insulin resistance and hyperandrogenism.[4,5] With a global prevalence estimated between 11% and 13%,[6] PCOS has a substantial impact on reproductive health and is associated with increased long-term risks of type 2 diabetes and cardiovascular disease.[7] Emerging evidence also indicates a higher prevalence of mental health disorders, particularly anxiety and depression, among women with PCOS.[8] Diagnosis is based on the Rotterdam criteria, requiring at least two of the following: clinical or laboratory evidence of hyperandrogenism, irregular ovulation, and polycystic ovarian morphology on ultrasound.[9] As a chronic and often lifelong condition, PCOS necessitates continuous management to control symptoms and prevent long-term complications, such as metabolic syndrome, type 2 diabetes mellitus, and cardiovascular disease.[9–12] Regular monitoring of metabolic health and reproductive function is critical to achieving optimal clinical outcomes.[13] The growing burden of PCOS, particularly during adolescence, underscores the importance of early detection and targeted interventions aimed at preventing its long-term sequelae.[14]

Despite the increasing recognition of PCOS as a global public health concern, existing research has predominantly concentrated on adult women, resulting in a limited understanding of the disease burden among adolescents.[15,16] While numerous studies have examined the prevalence and clinical outcomes of PCOS in adult populations, few have systematically investigated its impact during adolescence.[17,18] Furthermore, much of the available research is geographically restricted, offering little insight into how socio-economic disparities influence the prevalence and severity of PCOS across diverse settings.[19,20] The absence of a comprehensive, global assessment of adolescent PCOS has hindered the formulation of age-specific public health strategies and interventions.

To address these gaps, this study utilizes data from the Global Burden of Disease (GBD) Study 2021 to evaluate the global burden of adolescent PCOS from 1990 to 2021. This database is uniquely suited for this purpose due to its comprehensive geographic coverage across 204 countries, rigorous modeling framework (DisMod-MR), and inclusion of the Socio-demographic Index (SDI), which together enable consistent cross-national comparisons, robust trend analysis, and examination of health inequalities that previous geographically restricted studies could not achieve.[21,22] By examining trends in incidence, prevalence, and disability-adjusted life years (DALYs), the study aims to provide a detailed and geographically comparative analysis of adolescent PCOS burden worldwide.[21,22] In addition, it investigates the relationship between socio-demographic factors such as the SDI and disease burden, offering insights into regional disparities and the role of healthcare access in shaping disease outcomes.[23,24] Beyond retrospective trend analysis, forecasting the future disease burden is essential for proactive public health planning. Projecting the trajectory of adolescent PCOS to 2041 allows policymakers to anticipate future healthcare needs, allocate resources efficiently, and design timely preventive interventions. This forward-looking perspective aligns with our research objective of providing actionable evidence for long-term health policy development, particularly in regions where PCOS burden is rising most rapidly. This study offers several novel contributions that distinguish it from previous GBD-based PCOS analyses: First, it provides the first exclusive focus on the adolescent population (10–19 years), addressing a critical gap identified in recent clinical guidelines.[14,25] Second, it represents the first application of health inequality metrics and frontier analysis to adolescent PCOS, revealing disparities that simple trend analysis cannot capture. Third, it identifies Southeast Asia as the fastest-growing region—a finding with direct policy implications. The findings are expected to inform the development of evidence-based public health policies and clinical strategies focused on improving early diagnosis, prevention, and management of PCOS among adolescents globally.

The findings from this research are anticipated to inform public health interventions and guide healthcare resource allocation to address the growing burden of adolescent PCOS, particularly in low- and middle-income countries. Analyzing changes over time and variations across regions in adolescent PCOS is crucial for formulating targeted and effective interventions. Such efforts are key to alleviating the global burden of the condition and enhancing both long-term health outcomes and quality of life for adolescent girls worldwide.[25]

Methods

Data Source

Data for this study were obtained from the GBD Study 2021. Using the GBD Results Tool (http://ghdx.healthdata.org/gbd-results-tool), we extracted data on incidence, prevalence, and DALYs for PCOS among adolescents aged 10 to 19 years, covering the period from 1990 to 2021. The retrieved data included global, regional, and country-level estimates, stratified by the 21 GBD regions and by SDI quintiles.

The GBD 2021 estimates are derived using standardized modeling approaches, including DisMod-MR for epidemiological parameters and the Cause of Death Ensemble model (CODEm) for mortality data.[22,26–28] Detailed descriptions of these methodologies have been published previously.[22,26] All estimates comply with the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER) to ensure transparency and reproducibility.[29] As this study involved secondary analysis of publicly available aggregate data, ethical approval was not required.

Statistical Analysis

All statistical analyses and visualizations were performed using R version 4.4.2. A 95% uncertainty interval (UI) was calculated for each estimate, with all rates standardized per 100,000 population. Two-sided statistical tests were performed, with a $p < 0.05$ considered indicative of statistical significance. The primary objective of this study was to examine temporal trends in the prevalence, incidence, and DALYs of adolescent PCOS from 1990 to 2021. The estimated annual percentage change (EAPC) is a commonly used metric to quantify trends in age-standardized rates (ASRs).[30,31] EAPC was calculated by fitting a linear regression model to the natural logarithm of the ASR over time, as follows:

The EAPC was derived by applying a linear regression model to the natural logarithm of the ASR across the time period, using the following formula:

$$ln(ASR) = \alpha + \beta x + \varepsilon$$

$$EAPC = 100 \times exp(\beta) - 1$$

In where x refers to the calendar year, α- the intercept, β- the slope, ε- the random error, and the ASR was obtained as follows:

$$ASR = \frac{\sum_{i=1}^{A} aiwi}{\sum_{i=1}^{A} wi} \times 100,000$$

(In the ith age subgroup, ai is represented as age class. wi denotes the number of persons (or weight), where i is equal to the selected reference standard population).[32] The 95% confidence intervals (CIs) for the EAPC are derived from this fitted model. Trends were interpreted based on the 95% confidence interval (CI) of the EAPC: a lower bound of the CI greater than 0 indicates a statistically significant increasing trend, whereas an upper bound less than 0 suggests a statistically significant decreasing trend. If the 95% CI includes 0, the trend is considered statistically non-significant.[33]

To assess inequality, data on total cases of adolescent PCOS were collected and analyzed. In accordance with World Health Organization recommendations, two standard measures the Slope Index of Inequality (SII) and the Concentration Index were applied to assess absolute and relative income-related disparities across countries.[34] The SII represents the slope of the regression line relating country-level adolescent PCOS-related rates to the weighted rank of each country. To adjust for differences in burden magnitude, the SII is normalized by the global incidence, prevalence, and DALYs rates, producing the corresponding Relative Index of Inequality. In parallel, the Concentration Index measures the relative inequality in adolescent PCOS burden across countries by fitting a Lorenz concentration curve based on the cumulative distribution of disease burden and population. This index ranges from −1 to 1, where negative values indicate a disproportionate concentration of the adolescent PCOS burden in countries with higher SDI scores. In order to assess the association between adolescent PCOS burden and socio-demographic development, we performed a frontier analysis based on data spanning from 1990 to 2021. This analysis, based on ASRs and the SDI, aimed to identify potential improvements in adolescent PCOS ASRs achievable within specific countries or regions.

To predict the future trends of three age-standardized adolescent PCOS indicators over the next two decades, the autoregressive integrated moving average (ARIMA) model was applied. This approach effectively models temporal patterns and seasonal variations in time series data by combining three elements: autoregression (AR), differencing (I), and moving average (MA). The model's parameters p, d, and q correspond to the autoregressive order, differencing degree, and moving average order, respectively.[35] Stationarity of the series was evaluated using the Augmented Dickey-Fuller (ADF) test, while the autocorrelation function (ACF) and partial autocorrelation function (PACF) guided the selection of appropriate values for p and q. Optimal ARIMA models were identified based on the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), which were then used to forecast the burden of adolescent PCOS from 2022 through 2041. Model adequacy was confirmed by the Ljung–Box Q test, which indicated that the residuals followed an independent and normally distributed pattern.

Results

Overview of the Global Burden

Figure 1A and B illustrates the age-standardized incidence rate (ASIR) of adolescent PCOS across various countries and regions. As presented in Table 1, the worldwide incidence of adolescent PCOS demonstrated a significant increase throughout the 30-year span from 1990 to 2021. In 1990, the estimated number of incident cases worldwide was approximately 1,388,800 (95% UI: 988,011–1,965,769), corresponding to an ASIR of 268.64 per 100,000 population (95% UI: 191.12–380.25). By 2021, incident cases had risen to 2,181,799 (95% UI: 1,552,159–3,064,981), with the ASIR increasing to 348.21 per 100,000 population (95% UI: 247.72–489.16). The EAPC in ASIR from 1990 to 2021 was 0.81% (95% CI: 0.79–0.83), indicating a gradual increase in ASIR over the study period, consistent with the overall increase in the number of cases.

Figure 1C and D illustrates the age-standardized prevalence rate (ASPR) of adolescent PCOS across various countries and regions. As shown in Table 2, the global prevalence of adolescent PCOS has experienced substantial growth over the

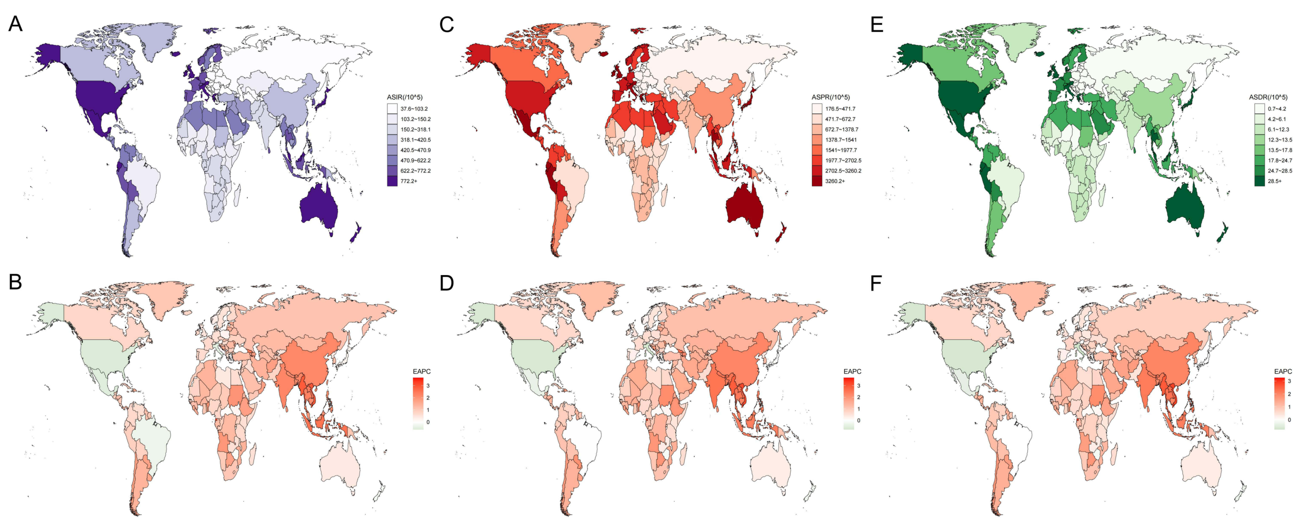

Figure 1 Global burden of adolescent PCOS in 204 countries and territories. (**A**) ASIR of adolescent PCOS in 2021. (**B**) EAPC of ASIR for adolescent PCOS from 1990 to 2021. (**C**) ASPR of adolescent PCOS in 2021. (**D**) EAPC of ASPR for adolescent PCOS from 1990 to 2021. ASPR. (**E**) ASDR of adolescent PCOS in 2021. (**F**) EAPC of ASDR for adolescent PCOS from 1990 to 2021.

Abbreviations: ASIR, age-standardized incidence rate; ASPR, age-standardized prevalence rate; ASDR, age-standardized DALYs rate; DALYs, disability-adjusted Life Years; EAPC, estimated annual percentage change; PCOS, polycystic ovary syndrome.

Table 1 Incidence of PCOS in 1990 and 2021 for Adolescence and All Locations, with EAPC from 1990 to 2021

Location	1990		2021		EAPC % (95% CI) 1990–2021
	Cases (95% UI)	Age-Standardized Incidence per 100,000 Population (95% UI)	Cases (95% UI)	Age-Standardized Incidence per 100,000 Population (95% UI)	
Global	1388799.86 (988,011.35–1,965,768.65)	268.64 (191.12–380.25)	2,181,798.58 (1,552,159.44–3,064,981.48)	348.21 (247.72–489.16)	0.81 (0.79–0.83)
SDI					
Low SDI	54664.46 (36,360.27–81,186.02)	98.23 (65.34–145.89)	187,798.57 (126,747.22–273,748.67)	143.15 (96.62–208.67)	1.31 (1.28–1.33)
Low-middle SDI	190398.09 (130,134.96–276,650.36)	150.76 (103.04–219.05)	446,591.17 (310,114.41–638,172.76)	242.29 (168.24–346.22)	1.65 (1.61–1.69)
Middle SDI	471680.57 (329,179.04–672,782.78)	259.6 (181.17–370.28)	772,298.19 (537,359.1–1,094,921.96)	427.84 (297.69–606.56)	1.67 (1.63–1.71)
High-middle SDI	243468.84 (170,714.96–344,069.09)	267.34 (187.45–377.81)	289,277.8 (201,453.86–411,868.87)	402.76 (280.48–573.44)	1.64 (1.55–1.74)
High SDI	427614.9 (308,560.21–601,548.81)	691.96 (499.31–973.41)	484,231.59 (357,771.02–664,722.83)	831.12 (614.07–1140.91)	0.14 (−0.04–0.31)
Region					
Andean Latin America	24818.43 (16,914.43–35,731.3)	569.6 (388.2–820.05)	41,841.58 (28,913.09–59,818.9)	760.03 (525.19–1086.58)	0.86 (0.77–0.96)
Australasia	15738.45 (11,531.15–20,670.34)	1005.32 (736.57–1320.36)	21,218.18 (15,143.16–29,348.45)	1159.08 (827.22–1603.21)	0.27 (0.18–0.35)
Caribbean	8775.14 (5874.58–12,648.61)	241.53 (161.69–348.14)	11,424.92 (7617.35–16,276.97)	307.22 (204.83–437.69)	0.83 (0.76–0.9)
Central Asia	4749.18 (3050.02–7183.78)	69.75 (44.79–105.5)	7277.68 (4783.95–10,571.74)	98.96 (65.05–143.75)	1.23 (1.15–1.3)
Central Europe	3632.67 (2234.41–5686.34)	36.63 (22.53–57.34)	2737.77 (1822.87–4028.27)	46.53 (30.98–68.47)	0.73 (0.69–0.77)
Central Latin America	116844.44 (79,665.99–166,506.96)	605.9 (413.11–863.42)	139,660.71 (96,857.21–197,759.01)	647.84 (449.29–917.34)	−0.17 (−0.34–0)
Central Sub-Saharan Africa	5402.16 (3571.77–8095.48)	87.3 (57.72–130.82)	22,151.24 (14,768.81–32,712.43)	136.97 (91.32–202.28)	1.39 (1.22–1.56)
East Asia	190611.29 (129,967.02–278,087.88)	165.91 (113.13–242.05)	246,901.41 (168,630.41–355,762.18)	318.57 (217.58–459.03)	2.16 (2–2.32)
Eastern Europe	5744.27 (3425.17–9059.47)	36.22 (21.6–57.12)	5397.65 (3328.3–8490.39)	47.88 (29.53–75.32)	1.12 (1.06–1.18)
Eastern Sub-Saharan Africa	23059.09 (15,141.87–34,403.93)	101.84 (66.87–151.94)	69,697.32 (46,641.13–102,042.24)	134.51 (90.01–196.93)	0.96 (0.91–1)
High-income Asia Pacific	156725.22 (109,242.4–224,986.71)	1140.61 (795.04–1637.4)	105,448.55 (74,153.43–150,513.54)	1313.03 (923.35–1874.18)	0.41 (0.32–0.49)
High-income North America	131175.09 (91,875.49–185,071.72)	680.81 (476.84–960.54)	200,195.38 (147,554.73–267,943.84)	868.17 (639.89–1161.97)	−0.53 (−1.01–0.04)
North Africa and Middle East	124040.24 (84,777.6–179,922.71)	326.28 (223.01–473.28)	234,043.99 (161,789.34–335,736.36)	431.72 (298.44–619.3)	0.99 (0.94–1.04)
Oceania	1929.65 (1309.05–2772.44)	272.59 (184.92–391.65)	5128.37 (3507.07–7288.54)	387.99 (265.33–551.42)	0.89 (0.73–1.05)
South Asia	142795.01 (98,610.06–208,062.09)	125.76 (86.85–183.24)	377,449.38 (262,171.37–537,933.79)	221.42 (153.79–315.56)	2.09 (1.97–2.22)
Southeast Asia	165317.67 (114,801.37–237,679.1)	321.18 (223.04–461.76)	345,431.11 (242,421.38–487,474.23)	618.72 (434.21–873.14)	2.44 (2.32–2.55)
Southern Latin America	11959.76 (8210.56–17,170.13)	260.33 (178.72–373.74)	20,904.19 (14,588.49–30,414.25)	422.41 (294.79–614.57)	1.53 (1.31–1.75)
Southern Sub-Saharan Africa	10782.54 (7254.83–15,793.77)	175.08 (117.8–256.45)	16,827.16 (11,397.06–24,693.35)	224.73 (152.21–329.79)	0.82 (0.72–0.91)
Tropical Latin America	19845.32 (12,892.94–29,848.67)	118.54 (77.01–178.29)	20,478.93 (13,399.9–30,023.28)	127.62 (83.5–187.09)	−0.27 (−0.45–0.09)
Western Europe	203064.1 (142,783.29–283,121.74)	802.44 (564.23–1118.8)	202,708.07 (142,199.19–284,459.47)	877.9 (615.84–1231.95)	0.18 (0.13–0.22)
Western Sub-Saharan Africa	21790.14 (14,270.13–32,587.5)	97.82 (64.06–146.3)	84,874.98 (56,651.64–124,406.17)	142.73 (95.27–209.21)	0.95 (0.75–1.14)

Abbreviations: UI, Uncertainty interval; CI, Confidence interval; EAPC, Estimated annual percent change; SDI, Socio demographic index; PCOS, Polycystic ovary syndrome.

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Table 2 Prevalence of PCOS in 1990 and 2021 for Adolescence and All Locations, with EAPC from 1990 to 2021

Location	1990		2021		EAPC % (95% CI) 1990–2021
	Cases (95% UI)	Age-Standardized Prevalence per 100,000 Population (95% UI)	Cases (95% UI)	Age-Standardized Prevalence per 100,000 Population (95% UI)	
Global	6082736.65 (4,029,213.16–9,002,648.26)	1176.61 (779.39–1741.43)	9,563,819.04 (6,371,244.8–14,070,360.58)	1526.36 (1016.84–2245.6)	0.89 (0.85–0.93)
SDI					
Low SDI	238344.79 (147,545.93–365,527.6)	428.29 (265.13–656.83)	847,068.54 (540,274.71–1,252,754.27)	645.69 (411.83–954.93)	1.39 (1.36–1.41)
Low-middle SDI	841038.39 (545,148.12–1,244,047.35)	665.93 (431.65–985.03)	2,072,636.6 (1,370,625.3–3,071,430.93)	1124.45 (743.6–1666.32)	1.8 (1.76–1.84)
Middle SDI	2141726.22 (1,421,054.69–3,158,106.3)	1178.74 (782.11–1738.13)	3,501,520.39 (2,307,887.63–5,134,011.76)	1939.77 (1278.52–2844.14)	1.75 (1.67–1.83)
High-middle SDI	1150121.35 (765,709.67–1,704,434.85)	1262.89 (840.79–1871.56)	1,289,796.77 (851,959.96–1,884,872.67)	1795.78 (1186.18–2624.3)	1.52 (1.37–1.66)
High SDI	1707016.95 (1,137,084.04–2,560,569.63)	2762.26 (1840.01–4143.46)	1,845,565.7 (1,284,584.18–2,670,444.72)	3167.68 (2204.83–4583.48)	0.12 (−0.02–0.27)
Region					
Andean Latin America	108964.71 (72,390.16–159,441.12)	2500.81 (1661.4–3659.27)	190,816.26 (126,387.8–280,390.84)	3466.1 (2295.78–5093.18)	1.07 (0.98–1.16)
Australasia	62230.41 (41,709.73–88,940.53)	3975.08 (2664.29–5681.24)	79,720.08 (53,184.53–118,938.19)	4354.84 (2905.29–6497.19)	0.19 (0.08–0.3)
Caribbean	44487.54 (28,829.68–64,625.75)	1224.48 (793.51–1778.77)	56,053.09 (36,374.2–81,825.05)	1507.29 (978.12–2200.31)	0.89 (0.81–0.98)
Central Asia	22006.28 (13,194.52–34,172.19)	323.18 (193.77–501.85)	33,413.6 (20,719.29–50,509.03)	454.35 (281.74–686.82)	1.42 (1.29–1.55)
Central Europe	17045.29 (9584.39–28,054.32)	171.88 (96.64–282.89)	13,118.02 (8305.26–19,758.01)	222.96 (141.16–335.82)	0.85 (0.72–0.98)
Central Latin America	544577.57 (355,907.97–796,489.75)	2823.92 (1845.57–4130.21)	680,715.02 (450,287.58–965,947.53)	3157.63 (2088.75–4480.73)	−0.02 (−0.19–0.15)
Central Sub-Saharan Africa	23660.75 (14,335.66–36,787.91)	382.36 (231.66–594.49)	99,083.81 (62,348.3–151,264.8)	612.69 (385.54–935.36)	1.48 (1.34–1.63)
East Asia	907327.96 (586,889.37–1,358,503.45)	789.76 (510.84–1182.47)	1,072,194.81 (695,407.78–1,592,670.61)	1383.41 (897.26–2054.96)	2.19 (1.88–2.51)
Eastern Europe	25300.08 (14,307.35–43,715.61)	159.53 (90.22–275.65)	23,436.63 (13,695.15–39,020.92)	207.91 (121.49–346.16)	1.2 (0.99–1.4)
Eastern Sub-Saharan Africa	101522.23 (61,975.76–156,441.32)	448.35 (273.7–690.89)	315,342.38 (196,883.75–470,806.47)	608.59 (379.97–908.62)	0.95 (0.9–1)
High-income Asia Pacific	557359.72 (379,022.16–807,686.52)	4056.33 (2758.43–5878.15)	351,740.1 (242,523.22–499,593.2)	4379.83 (3019.87–6220.88)	0.14 (0.01–0.28)
High-income North America	522548.74 (340,830.17–792,962.16)	2712.07 (1768.94–4115.54)	716,422.04 (497,484.18–1,002,828.22)	3106.86 (2157.41–4348.9)	−0.61 (−1.03–0.18)
North Africa and Middle East	583342.83 (378,179.97–863,319.78)	1534.47 (994.79–2270.94)	1,122,718.05 (742,419.79–1,641,876.14)	2070.96 (1369.46–3028.6)	1.11 (0.98–1.23)
Oceania	8374.83 (5396.29–12,335.93)	1183.07 (762.31–1742.64)	21,914.97 (14,336.73–31,965.89)	1658.01 (1084.67–2418.43)	0.9 (0.74–1.06)
South Asia	638519.61 (409,494.82–954,802.84)	562.34 (360.64–840.89)	1,802,758.59 (1,171,154.42–2,659,687.5)	1057.53 (687.02–1560.22)	2.35 (2.23–2.47)
Southeast Asia	676724.47 (453,290.06–1,021,178.48)	1314.74 (880.66–1983.95)	1,454,553.06 (954,680.99–2,140,303.79)	2605.33 (1709.98–3833.61)	2.46 (2.38–2.55)
Southern Latin America	45371.02 (29,957.38–69,763.87)	987.59 (652.08–1518.55)	80,122.89 (52,325.8–117,865.13)	1619.02 (1057.33–2381.67)	1.59 (1.36–1.81)
Southern Sub-Saharan Africa	49091.96 (30,747.34–74,288.97)	797.12 (499.26–1206.26)	73,518.03 (46,042.24–111,577.26)	981.86 (614.91–1490.15)	0.89 (0.7–1.07)
Tropical Latin America	89425.96 (55,423.55–137,462.89)	534.14 (331.05–821.07)	96,721.59 (61,602.68–145,795.89)	602.73 (383.88–908.54)	0.01 (−0.14–0.16)
Western Europe	958489.99 (642,213.38–1,386,356.53)	3787.62 (2537.81–5478.4)	895,743.88 (601,374.52–1,298,737.16)	3879.34 (2604.47–5624.65)	0 (−0.02–0.03)
Western Sub-Saharan Africa	96364.7 (58,399.34–148,581.4)	432.62 (262.18–667.04)	383,712.13 (239,753.2–576,298.85)	645.27 (403.18–969.13)	0.96 (0.74–1.18)

Abbreviations: UI, Uncertainty interval; CI, Confidence interval; EAPC, Estimated annual percent change; SDI, Socio demographic index; PCOS, Polycystic ovary syndrome.

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31-year period from 1990 to 2021. In 1990, the estimated number of prevalent cases worldwide was approximately 6,082,737 (95% UI: 4,029,213–9,002,648), corresponding to an ASPR of 1,176.61 per 100,000 population (95% UI: 779.39–1,741.43). By 2021, prevalent cases increased to 9,563,819 (95% UI: 6,371,245–14,070,361), with the ASPR rising to 1,526.36 per 100,000 population (95% UI: 1,016.84–2,245.60). The EAPC in ASPR between 1990 and 2021 was 0.89% (95% CI: 0.85–0.93), reflecting a consistent increase in prevalence in line with the rising case numbers.

Figure 1E and F provides a comprehensive overview of the age-standardized DALYs rate (ASDR) of adolescent PCOS across various countries and regions. As detailed in Table 3, the global burden of adolescent PCOS, measured by DALYs, demonstrated a rising trend from 1990 to 2021. In 1990, the estimated global DALYs attributable to adolescent PCOS were 54,442 (95% UI: 23,749–114,624), with an ASDR of 10.53 per 100,000 population (95% UI: 4.59–22.17). By 2021, DALYs increased to 85,321 (95% UI: 37,289–180,342), accompanied by an ASDR of 13.62 per 100,000 population (95% UI: 5.95–28.78). The EAPC in ASDR over the study period was 0.88% (95% CI: 0.83–0.93), indicating a consistent upward trend in the DALY rate over the study period, mirroring the overall rise in DALY numbers.

PCOS Burden by SDI Quintile

Figures S1–S3 depict the incidence, prevalence, and DALYs of adolescent PCOS across different SDI quintiles from 1990 to 2021, highlighting notable disparities in disease burden. Detailed metrics are provided in Tables 1–3, illustrating regional differences and temporal trends. The Low SDI region recorded the lowest ASIR in 1990 at 98.23 per 100,000 population (95% UI: 65.34–145.89), which increased to 143.15 per 100,000 (95% UI: 96.62–208.67) by 2021, with an EAPC of 1.31% (95% CI: 1.28–1.33). Similarly, the Low-middle SDI region's ASPR rose from 428.29 per 100,000 (95% UI: 265.13–656.83) in 1990 to 645.69 per 100,000 (95% UI: 411.83–954.93) in 2021, corresponding to an EAPC of 1.39% (95% CI: 1.36–1.41). The ASDR in the Low SDI region also increased from 3.88 per 100,000 (95% UI: 1.64–8.29) in 1990 to 5.80 per 100,000 (95% UI: 2.48–12.14) in 2021, with an EAPC of 1.35% (95% CI: 1.33–1.37). In contrast, the High SDI region, despite having the highest baseline rates, exhibited minimal changes: ASIR increased from 691.96 per 100,000 (95% UI: 499.31–973.41) in 1990 to 831.12 per 100,000 (95% UI: 614.07–1140.91) in 2021, with an EAPC of 0.14% (95% CI: −0.04–0.31). The Middle SDI region showed the most pronounced rise in ASIR, with an EAPC of 1.67% (95% CI: 1.63–1.71). These findings reveal a distinct gradient in growth patterns: while high SDI regions exhibit near-stabilization of disease burden (EAPC: 0.14%), middle- and low-SDI regions continue to experience rapid increases, indicating that the global rise in adolescent PCOS is increasingly driven by accelerating rates in less developed settings. These findings underscore the urgent need for targeted interventions in regions experiencing a higher burden of disease and rapid increases in PCOS incidence and prevalence.

PCOS Burden in the 21 GBD Regions

Figures S4–S6 and Tables 1–3 display the incidence, prevalence, and DALYs of adolescent PCOS across 21 regions between 1990 and 2021, emphasizing notable differences in disease burden among regions. In 1990, Western Europe exhibited the highest burden, with an estimated 203,064 cases (95% UI: 142,783–283,122) and an ASIR of 802.44 per 100,000 population (95% UI: 564.23–1,118.80). The ASPR stood at 3,787.62 per 100,000 (95% UI: 2537.81–5478.40), corresponding to 958,490 prevalent cases (95% UI: 642,213–1,386,357). DALYs were estimated at 8419 (95% UI: 3648–17965), with an ASDR of 33.27 per 100,000 population (95% UI: 14.42–70.99). By 2021, these figures showed slight variation: incidence cases were 202,708 (95% UI: 142,199–284,459) with an ASIR of 877.90 per 100,000 (95% UI: 615.84–1231.95); prevalence cases decreased slightly to 895,744 (95% UI: 601375–1298,737) with an ASPR of 3,879.34 per 100,000 (95% UI: 2604.47–5624.65); and DALYs numbered 7876 (95% UI: 3402–16639), with an ASDR of 34.11 per 100,000 (95% UI: 14.73–72.06). The EAPCs for the period were 0.18% (95% CI: 0.13–0.22) for incidence, 0.00% (95% CI: −0.02–0.03) for prevalence, and 0.01% (95% CI: −0.02–0.04) for DALYs, indicating a relatively stable disease burden over the three decades. In contrast, Oceania had the lowest incidence, prevalence, and DALYs of adolescent PCOS in 1990, with an estimated 19,296.5 cases (95% UI: 13,090.5–27,724.4) and an ASIR of 272.59 per 100,000 population (95% UI: 184.92–391.65). The ASPR was 1183.07 per 100,000 population (95% UI: 762.31–1742.64), corresponding to 8374.8 prevalent cases (95% UI: 5,396.2–12,335.9). DALYs were 74.1 (95% UI: 30.9–161.9), with an ASDR of 10.47 per 100,000 population (95% UI: 4.36–22.87). By 2021, these figures had increased

Table 3 DALYs of PCOS in 1990 and 2021 for Adolescence and All Locations, with EAPC from 1990 to 2021

Location	1990		2021		EAPC % (95% CI) 1990–2021
	Cases (95% UI)	Age-Standardized DALYs per 100,000 Population (95% UI)	Cases (95% UI)	Age-Standardized DALYs per 100,000 Population (95% UI)	
Global	54442.15 (23,749.14–114,623.78)	10.53 (4.59–22.17)	85,321.45 (37,288.87–180,342.14)	13.62 (5.95–28.78)	0.88 (0.83–0.93)
SDI					
Low SDI	2160.65 (910.75–4610.74)	3.88 (1.64–8.29)	7611.73 (3248–15,924.02)	5.8 (2.48–12.14)	1.35 (1.33–1.37)
Low-middle SDI	7731.22 (3322.76–16,082.59)	6.12 (2.63–12.73)	18,703.28 (8108.96–39,651.81)	10.15 (4.4–21.51)	1.74 (1.71–1.78)
Middle SDI	19281.07 (8312.21–40,622.41)	10.61 (4.57–22.36)	31,270.93 (13,452.55–66,439.88)	17.32 (7.45–36.81)	1.72 (1.64–1.81)
High-middle SDI	10244.4 (4426.97–21,680.88)	11.25 (4.86–23.81)	11,465.1 (4940.95–24,536.92)	15.96 (6.88–34.16)	1.51 (1.36–1.66)
High SDI	14984.09 (6483.99–31,227.5)	24.25 (10.49–50.53)	16,205.57 (7079.87–33,722.82)	27.81 (12.15–57.88)	0.13 (−0.01–0.28)
Region					
Andean Latin America	949.48 (407.87–2086.29)	21.79 (9.36–47.88)	1667.22 (726.08–3506.78)	30.28 (13.19–63.7)	1.07 (0.97–1.17)
Australasia	542.83 (228.53–1110.74)	34.67 (14.6–70.95)	693.9 (298.54–1452.87)	37.91 (16.31–79.37)	0.2 (0.09–0.31)
Caribbean	408.17 (175.95–894.44)	11.23 (4.84–24.62)	507.72 (223.49–1098.41)	13.65 (6.01–29.54)	0.88 (0.78–0.98)
Central Asia	200.27 (80.22–421.33)	2.94 (1.18–6.19)	302.31 (125.77–667.94)	4.11 (1.71–9.08)	1.38 (1.25–1.51)
Central Europe	155.27 (61.44–325.73)	1.57 (0.62–3.28)	118.21 (50.11–253.12)	2.01 (0.85–4.3)	0.84 (0.71–0.97)
Central Latin America	4787.49 (2123.15–10,116.23)	24.83 (11.01–52.46)	5977.78 (2700.52–12,679.91)	27.73 (12.53–58.82)	−0.02 (−0.19–0.15)
Central Sub-Saharan Africa	211.25 (85.63–470.94)	3.41 (1.38–7.61)	887.07 (380.7–1881.55)	5.49 (2.35–11.63)	1.48 (1.33–1.62)
East Asia	8095.53 (3433.26–17,298.35)	7.05 (2.99–15.06)	9558.19 (4116.46–20,623.17)	12.33 (5.31–26.61)	2.19 (1.87–2.51)
Eastern Europe	241.98 (90.44–544.32)	1.53 (0.57–3.43)	223.37 (88.64–502.15)	1.98 (0.79–4.45)	1.18 (0.98–1.38)
Eastern Sub-Saharan Africa	911.33 (376.97–1956.16)	4.02 (1.66–8.64)	2814.92 (1175.95–5892.29)	5.43 (2.27–11.37)	0.92 (0.87–0.97)
High-income Asia Pacific	4869.31 (2108.12–10,096)	35.44 (15.34–73.48)	3074.06 (1307.81–6462.3)	38.28 (16.28–80.47)	0.15 (0.01–0.29)
High-income North America	4569.7 (1962.15–9463.86)	23.72 (10.18–49.12)	6264.91 (2831.57–12,774.51)	27.17 (12.28–55.4)	−0.59 (−1.01–0.17)
North Africa and Middle East	5362.46 (2285.81–11,264.67)	14.11 (6.01–29.63)	10,142.13 (4241.06–21,742.49)	18.71 (7.82–40.11)	1.08 (0.94–1.22)
Oceania	74.09 (30.85–161.91)	10.47 (4.36–22.87)	192.53 (83.49–411.77)	14.57 (6.32–31.15)	0.88 (0.72–1.04)
South Asia	5885.55 (2499.77–12,141.77)	5.18 (2.2–10.69)	16,229.18 (6826.7–34,192.06)	9.52 (4–20.06)	2.25 (2.14–2.35)
Southeast Asia	6236.42 (2695.42–12,849.11)	12.12 (5.24–24.96)	13,104.98 (5708.13–27,495.05)	23.47 (10.22–49.25)	2.38 (2.3–2.45)
Southern Latin America	398.62 (170.6–843.21)	8.68 (3.71–18.35)	703.03 (298.08–1432.98)	14.21 (6.02–28.96)	1.58 (1.35–1.8)
Southern Sub-Saharan Africa	445.06 (188.87–958.35)	7.23 (3.07–15.56)	654.17 (279.55–1429.77)	8.74 (3.73–19.1)	0.87 (0.67–1.07)
Tropical Latin America	804.5 (337.41–1712.01)	4.81 (2.02–10.23)	866.21 (357.63–1865.1)	5.4 (2.23–11.62)	0.03 (−0.12–0.18)
Western Europe	8419.17 (3647.92–17,964.62)	33.27 (14.42–70.99)	7875.97 (3402.11–16,639.46)	34.11 (14.73–72.06)	0.01 (−0.02–0.04)
Western Sub-Saharan Africa	873.69 (365.9–1893.46)	3.92 (1.64–8.5)	3463.6 (1470.2–7206.49)	5.82 (2.47–12.12)	0.93 (0.71–1.15)

Abbreviations: UI, Uncertainty interval; CI, Confidence interval; EAPC, Estimated annual percent change; SDI, Socio demographic index; PCOS, Polycystic ovary syndrome; DALYs, Disability-adjusted life years.

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to 51,283.7 cases (95% UI: 35,070.7–72,885.4) with an ASIR of 387.99 per 100,000 population (95% UI: 265.33–551.42), 21,914.9 prevalent cases (95% UI: 14,336.7–31,965.9) with an ASPR of 1,658.01 per 100,000 population (95% UI: 1084.67–2418.43), and 192.5 DALYs (95% UI: 83.5–411.8) with an ASDR of 14.57 per 100,000 population (95% UI: 6.32–31.15). The EAPCs for Oceania were 0.89% (95% CI: 0.73–1.05) for incidence, 0.90% (95% CI: 0.74–1.06) for prevalence, and 0.88% (95% CI: 0.72–1.04) for DALYs, reflecting a steady increase over the study period. Notably, Southeast Asia exhibited the most rapid increase in adolescent PCOS burden between 1990 and 2021, with EAPCs of 2.44% (95% CI: 2.32–2.55) for incidence, 2.46% (95% CI: 2.38–2.55) for prevalence, and 2.38% (95% CI: 2.30–2.45) for DALYs. This rate of increase is approximately three-fold higher than the global average (0.8–0.9%) and stands in stark contrast to Western Europe, where EAPCs remained below 0.2% across all metrics, highlighting substantial regional heterogeneity in the trajectory of adolescent PCOS burden. These findings highlight the urgent need for targeted public health interventions in regions experiencing both a high disease burden and rapid growth in PCOS incidence and prevalence, particularly in Southeast Asia.

PCOS Burden by Country or Territory

As presented in Tables S1–S3, a comprehensive analysis of adolescent PCOS incidence, prevalence, and DALYs across 204 countries revealed that Italy had the highest ASIR of 1965.12 per 100,000 population (95% UI: 1390.85–2758.27), ASPR of 10,019.08 per 100,000 (95% UI: 6640.19–14,529.77), and ASDR of 87.34 per 100,000 (95% UI: 37.94–186.16) in 1990. By 2021, these rates had decreased to an ASIR of 1844.8 (95% UI: 1290.39–2593.02), an ASPR of 8681.93 (95% UI: 5739.89–12555.83), and an ASDR of 75.95 (95% UI: 33.03–163.72) per 100,000 population. The EAPCs reflect a declining trend in Italy's adolescent PCOS burden over the three decades, with values of −0.5% (95% CI: −0.65 to −0.35) for incidence, −0.78% (95% CI: −0.9 to −0.66) for prevalence, and −0.76% (95% CI: −0.88 to −0.64) for DALYs, indicating some improvement in disease burden. Conversely, the Maldives experienced an increasing burden, with EAPCs of 3.65% (95% CI: 3.36–3.94) for incidence, 3.67% (95% CI: 3.21–4.13) for prevalence, and 3.43% (95% CI: 2.91–3.96) for DALYs, underscoring a growing public health challenge in this region. The contrast between Italy's declining trend and the Maldives' rapid growth—a more than seven-fold difference in the rate of increase—illustrates the extreme country-level heterogeneity that underlies the global trends, with implications for where preventive efforts should be prioritized.

Frontier Analysis of Age-standardized Rates

The analysis of ASRs for adolescent PCOS reveals that certain countries or regions maintain substantially lower disease burdens relative to their SDI, establishing a benchmark referred to as the "frontier" representing the optimal achievable burden within a given socio-demographic context. The effective difference, defined as the gap between a country's actual disease burden and this frontier, highlights the potential scope for reducing the ASR of adolescent PCOS. Larger effective differences indicate greater opportunities for improvement.

In 2021, a detailed assessment of ASR data alongside SDI levels identified countries with the most pronounced effective differences, thus pinpointing those with the highest potential to reduce disease burden. Italy, Japan, New Zealand, Australia, and Brunei Darussalam ranked as the top five regions exhibiting the largest effective differences in ASIR, ranging from 1820.69 to 921.83 (Table S4). Correspondingly, the top five regions for effective differences in ASPR and ASDR included Italy, New Zealand, Japan, Australia, and Malaysia, with ASPR differences spanning from 8667.40 to 3806.12 (Table S5) and ASDR differences ranging from 74.91 to 33.52 (Table S6). These pronounced disparities emphasize the considerable unrealized potential for reducing the adolescent PCOS burden and underscore the necessity for targeted, context-specific health interventions in these regions. This analysis not only illustrates the variability in disease burden but also reinforces the critical importance of tailored strategies to address inequities in adolescent PCOS.

As illustrated in Figure 2, the overall ASR of adolescent PCOS tends to increase with rising SDI, suggesting that countries with higher SDI generally experience a greater disease burden. Between 1990 and 2021, most regions exhibit a clear upward trend in ASR. Countries positioned closer to the frontier consistently maintain lower burdens, whereas those further from the frontier demonstrate less favorable trajectories. In these figures, the

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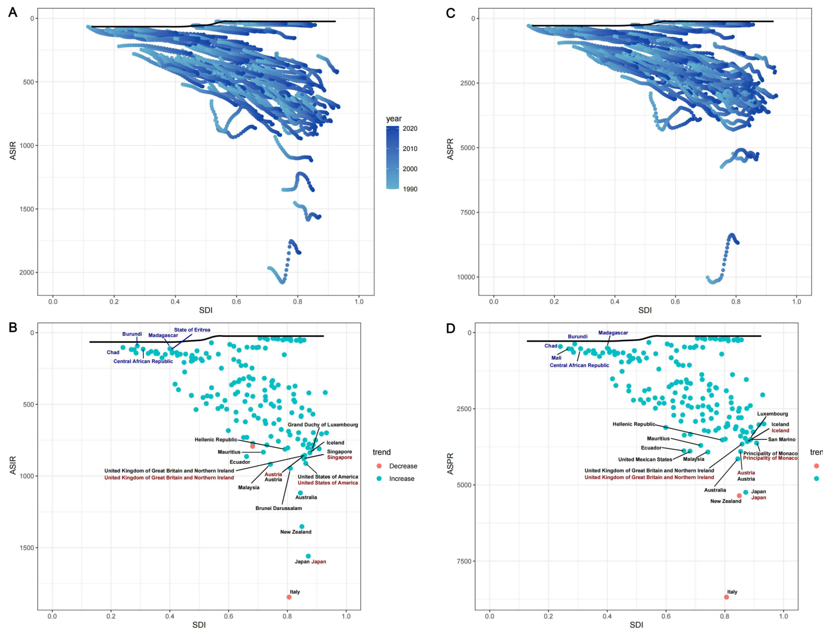

Figure 2 Global trends and frontier analysis of adolescent PCOS burden (1990–2021). (**A, C** and **E**) Temporal trends in ASIR, ASPR, and ASDR) from 1990 to 2021. (**B, D** and **F**) Frontier analysis of ASIR, ASPR, and ASDR in relation to the SDI in 2021. The solid black line represents the efficiency frontier, with each dot corresponding to a country or territory. The top 15 countries with the largest effective difference (greatest gap from the frontier) are labeled in black. Selected frontier countries with low SDI (<0.5) and minimal effective difference are highlighted in blue. Countries with high SDI (>0.85) but relatively large effective difference are highlighted in red. Dot colors indicate temporal trends: red dots denote decreasing ASR from 1990–2021, blue dots denote increasing ASR.

Abbreviations: SDI, Socio-demographic Index; ASIR, age-standardized incidence rate; ASPR, age-standardized prevalence rate; ASDR, age-standardized DALYs rate; DALYs, disability-adjusted life years; PCOS, polycystic ovary syndrome.

solid black line represents the frontier, and each dot corresponds to an individual country. Blue dots indicate countries with an increasing ASR trend, while red dots signify those with a decreasing trend, thereby reflecting relative progress or ongoing challenges in mitigating the disease burden over time.

Health Inequality Analysis

As illustrated in Figure 3 and detailed in Tables S7–S9, the SII for the incidence, prevalence, and DALYs of adolescent PCOS has shown a substantial rise over the last thirty years. Specifically, SII values rose from 359.32, 1624.51, and 14.36 in 1990 to 433.25, 1844.87, and 16.26 in 2021, respectively. These increases were statistically significant (p = 8.83e-07 for incidence, p = 2.64e-05 for prevalence and p = 2.91e-05 for DALYs), indicating a widening disparity in disease burden between higher and lower SDI regions. Concurrently, from 1990 to 2021, the Concentration Index for incidence, prevalence, and DALYs showed notable shifts: from approximately −0.26 to −0.21 for incidence, −0.25 to −0.19 for prevalence, and −0.25 to −0.19 for DALYs. These changes suggest that, although adolescent PCOS burden remains disproportionately higher in regions with greater SDI, the degree of inequality has somewhat diminished over time.

The ARIMA Model Predicts the ASRs for Adolescent PCOS

The ARIMA model was employed to forecast trends in three age-standardized indicators of adolescent PCOS over the next 20 years. The optimal model parameters, along with their corresponding AIC, BIC, and Ljung–Box test p-values, are detailed in Table 4. The Ljung–Box test verified that residuals from all models behaved as white noise, confirming their stability and indicating a robust fit to the observed data. Projected trends in ASRs of adolescent PCOS for the period 2022 to 2041 are shown in Figure 4. Over this period, the ASIR, ASPR, and ASDR are all projected to increase. Specifically, by 2041, the estimated ASIR is expected to reach 371.69 per 100,000 population, the ASPR 1732.68 per 100,000, and the ASDR 15.37 per 100,000. These projections suggest a continued upward trajectory, with the most rapid growth anticipated in regions that have already demonstrated the steepest increases over the past three decades. Detailed annual projections are provided in Supplementary Tables S10–S12.

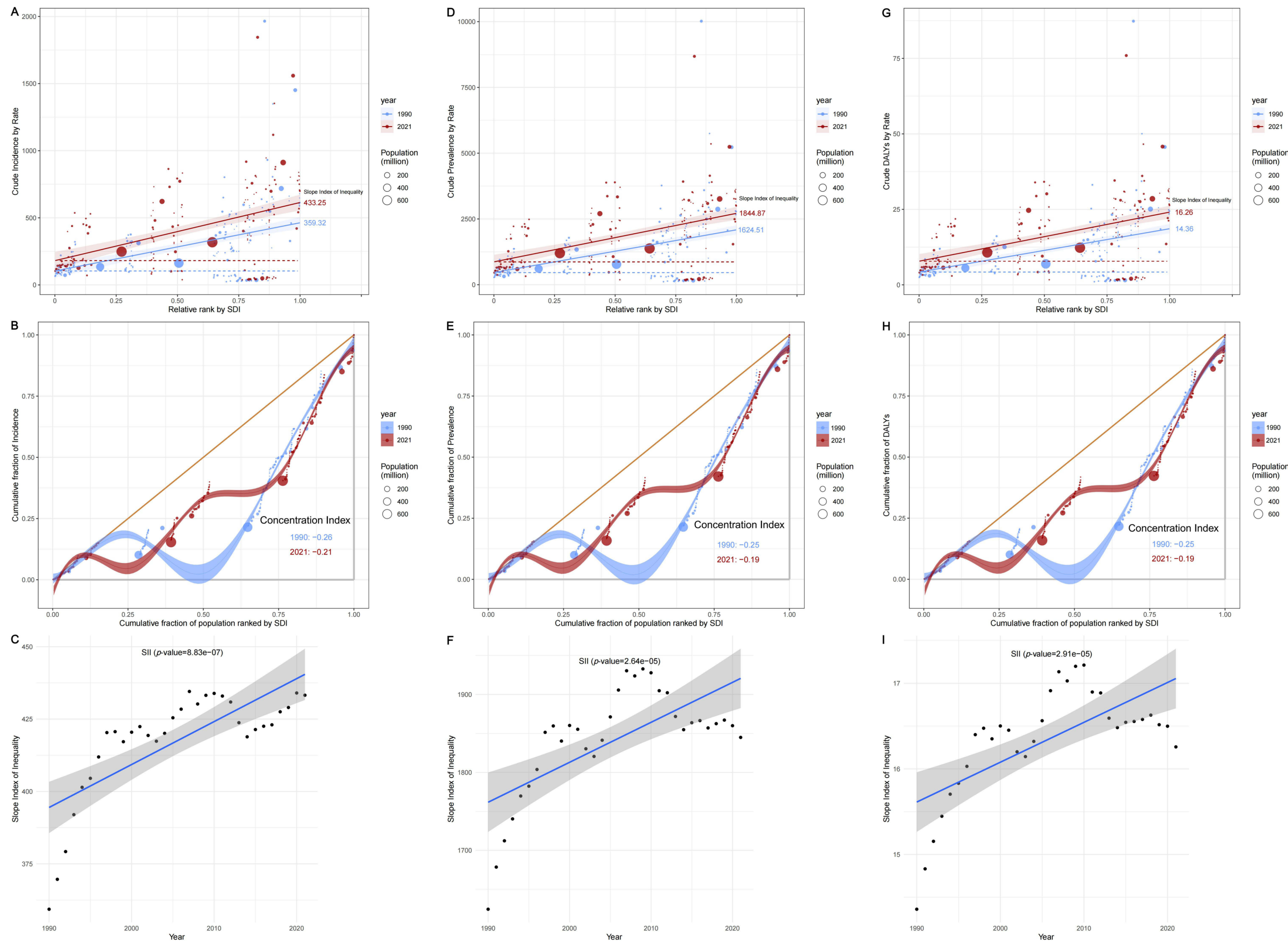

Figure 3 Health inequality analysis of adolescent PCOS burden (1990–2021). (**A, D** and **G**) Relationship between crude incidence, prevalence, and DALYs rates and countries' relative SDI rank in 1990 (blue) and 2021 (red). Each point represents a country, with point size indicating population size. Regression lines demonstrate an upward trend, indicating higher burden in higher-SDI countries. The Slope Index of Inequality (SII) quantifies absolute disparities across SDI ranks. (**B, E** and **H**) Concentration curves for incidence, prevalence, and DALYs burden against the cumulative population ranked by SDI in 1990 and 2021. The Concentration Index shifted from approximately −0.26 to −0.21 for incidence, −0.25 to −0.19 for prevalence, and −0.25 to −0.19 for DALYs, indicating a relative decrease in inequality over time as burden becomes more evenly distributed across SDI ranks. (**C, F** and **I**) Temporal trends of SII from 1990 to 2021. Black dots represent observed SII values; solid blue lines denote fitted linear regression; shaded areas indicate 95% confidence intervals. The upward trajectory of SII across all metrics (incidence: p = 8.83e-07; prevalence: p = 2.64e-05; DALYs: p = 2.91e-05) reflects widening absolute disparities between higher- and lower-SDI regions.
Abbreviations: SDI, Socio-demographic Index; PCOS, polycystic ovary syndrome; SII, Slope Index of Inequality; DALYs, disability-adjusted life years.

Discussion

By utilizing data from the GBD Study 2021, this thorough analysis delineates the burden of adolescent PCOS at global, regional, and national levels spanning the years 1990 to 2021. Our findings reveal a consistent rise in both the ASIR and ASPR over the three decades, accompanied by increasing DALYs, reflecting a growing global disease burden. Notably,

Table 4 ARIMA Model Parameters and Their Corresponding AIC and BIC for Prediction of ASIR, ASPR and ASDR (per 100,000) for PCOS in Adolescence for the Next 20 years

Measure	Parameters	AIC	BIC	Ljung-Box Test p-value
Incidence	ARIMA (0,2,1)	69.08	71.88	0.9389
Prevalence	ARIMA (1,1,0)	170.65	174.95	0.8718
DALYs	ARIMA (1,1,0)	−122.73	−118.43	0.7821

Abbreviations: ARIMA, Autoregressive integrated moving average; ASIR, Age-standardized incidence rate; ASPR, Age-standardized prevalence rate; ASDR, Age-standardized DALYs rate; PCOS, Polycystic ovary syndrome.

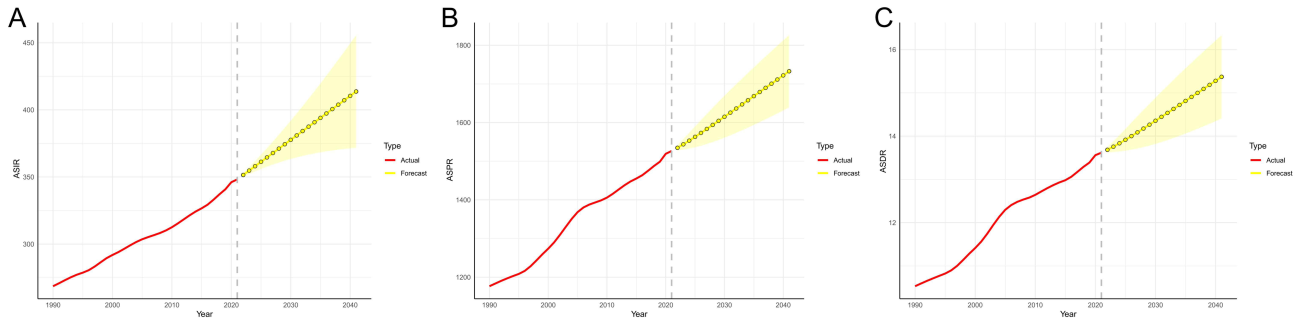

Figure 4 Forecast of adolescent PCOS ASIR, ASPR, and ASDR per 100,000 from 2022 to 2041 through ARIMA. (**A**) ASIR; (**B**) ASPR; (**C**) ASDR.
Abbreviations: PCOS, Polycystic ovary syndrome; ASIR, Age-standardized incidence rate; ASPR, Age-standardized prevalence rate; ASDR, Age-standardized DALYs rate; DALYs, disability-adjusted life years.

significant regional disparities were observed: Western Europe bore a higher baseline burden, whereas regions such as Southeast Asia experienced rapid increases. Health inequality assessments demonstrate a widening gap between high and low SDI regions. Frontier analysis further highlights areas with considerable potential to reduce disease burden. Additionally, projections derived from the ARIMA model suggest that the increasing trend will persist over the upcoming two decades, highlighting the critical need for focused interventions and additional research efforts.

Global trends in the adolescent PCOS burden indicate a widespread increase in both prevalence and incidence from 1990 to 2021, with marked disparities observed between high- and low-SDI countries. Our findings reveal two distinct patterns: Western Europe exhibits a stable, high-baseline burden, while Southeast Asia demonstrates rapid growth from a lower baseline. This contrast requires a nuanced explanation that considers both healthcare system factors and underlying epidemiological drivers. In contrast, the rapid growth in Southeast Asia is likely driven by a confluence of factors. High-SDI countries, particularly in Western Europe, have experienced a steady increase in the burden of adolescent PCOS, albeit at a slower rate compared to Southeast Asia, where the disease burden has risen sharply. This pattern suggests that while enhanced healthcare infrastructure and improved diagnostic capabilities in high-SDI countries contribute to higher detection rates, the rapid increase in low- and middle-SDI regions is likely driven by socio-economic transitions, urbanization, and lifestyle changes such as poor diet and decreased physical activity.[36] This is further corroborated by the rising obesity rates and related metabolic dysfunctions in Southeast Asia, both of which are established risk factors for PCOS.[37,38] Specifically, the region has undergone a rapid nutritional transition characterized by increased consumption of processed foods and high-glycemic diets, alongside declining physical activity accompanying urbanization. These lifestyle changes have contributed to rising adolescent obesity rates, a key metabolic driver of PCOS.[39] Furthermore, gradually improving but still limited diagnostic capacity in the region may be uncovering previously unrecognized cases, contributing to the observed upward trend. Notably, the timing of the accelerated increase in PCOS burden in Southeast Asia aligned closely with the region's period of rapid economic growth and concurrent lifestyle transitions.

The 2003 Rotterdam diagnostic criteria were widely used for diagnosing PCOS, but the sharp rise in the disease burden of adolescent PCOS may be linked to overdiagnosis.[40,41] The 2023 International Evidence-based PCOS Guideline emphasizes the diagnostic difficulties in adolescents, noting that typical physiological changes during this period may overlap with adult PCOS criteria, which can lead to delayed, overlooked, or possibly overdiagnosis. Although polycystic ovary morphology (PCOM) and anti-Müllerian hormone (AMH) levels are supported for diagnosing PCOS in adults, the guideline recommends against their use in adolescents to reduce the risk of overdiagnosis.[14] However, Assessment of PCOM and AMH levels may be appropriate in adolescents around eight years after menarche, a stage when the hypothalamic-pituitary-ovarian axis is fully developed and evidence-based criteria for PCOM can be reliably applied. Adolescents identified as "at risk" for PCOS based on clinical features such as menstrual irregularities and hyperandrogenism should undergo continuous follow-up to monitor their health outcomes.[25] Furthermore, the guideline underscores the importance of addressing emotional well-being by recommending routine screening for depression and other psychological conditions in adolescents with PCOS.[25,42] It also highlights the necessity of a comprehensive, lifelong management plan encompassing lifestyle interventions, timely metabolic risk assessments, and a coordinated transition to adult healthcare services.

In contrast to findings from other regions, our study identified a notably high disease burden of PCOS in Italy and Japan, despite both countries having well-established healthcare systems[43–46] Although a decline in the disease burden among Italian adolescents with PCOS was observed reflected by negative EAPCs for incidence, prevalence, and DALYs frontier analysis suggests substantial potential for further health improvements. This may be linked to lifestyle shifts, including a gradual departure from the traditional Mediterranean diet toward more Westernized dietary patterns in certain areas, which could contribute to increased obesity and metabolic complications, thereby exacerbating PCOS incidence.[47,48] Conversely, the Japanese Society of Obstetrics and Gynecology (JSOG) has recently revised the diagnostic criteria for PCOS to emphasize clinical manifestations and laboratory findings, aiming for more precise diagnoses. The JSOG criteria particularly highlight the significance of hyperandrogenism or elevated luteinizing hormone levels, aligning more closely with the phenotypic characteristics common in the East Asian population.[49] Despite adopting more stringent diagnostic standards, the burden of adolescent PCOS in Japan continues to rise. This increase is influenced by a combination of genetic predisposition, lifestyle changes, and cultural factors.[50,51] Traditionally, the Japanese diet rich in rice and fish has been associated with lower obesity rates and favorable metabolic profiles. However, the growing prevalence of processed foods, high-calorie diets, and Westernized eating habits in urban settings has contributed to rising obesity rates, a key risk factor for PCOS.[52,53] Additionally, rapid urbanization and a sedentary lifestyle in Japan have exacerbated the risk of metabolic dysfunction and insulin resistance, both of which are strongly associated with PCOS.[54] While Japan's advanced healthcare system facilitates higher detection rates through improved access to diagnostic tools, this may also contribute to an apparent increase in reported prevalence. Cultural pressures surrounding body image and femininity especially among Japanese adolescents influenced by Western media and societal norms intensify concerns about appearance, including anxiety related to obesity and eating disorders.[55] These pressures often motivate individuals to seek medical care for primarily aesthetic concerns, resulting in more diagnoses and thus contributing to the rising burden of conditions such as PCOS. This underscores the multifaceted nature of PCOS burden, shaped by an interplay of socio-economic, healthcare, and cultural factors. Complicating this picture further, recent research has found that much of the PCOS-related content on platforms like TikTok is misleading, of low quality, and lacks reliability, which can negatively influence adolescents' healthcare-seeking behaviors by disseminating inaccurate information.[56]

Previous research has identified a positive association between the SDI and the burden of PCOS, which may be partly explained by the higher consumption of Western-style diets in developed nations diets that are strongly associated with risk factors for PCOS, including obesity and insulin resistance.[46] Health inequality analyses revealed significant disparities in the burden of adolescent PCOS, with a widening gap between high- and low-SDI regions. Both the SII and concentration index indicate that regions with higher SDI generally experience greater disease burdens, likely reflecting better diagnostic capacity and healthcare access. Conversely, low-SDI regions, which often face limited healthcare access and lower awareness, are witnessing rapid increases in PCOS prevalence and incidence. These disparities highlight the critical need to improve healthcare infrastructure and accessibility in low-SDI countries, where underreporting and misdiagnosis may lead to underestimation of the true disease burden. The frontier analysis further underscores the significant potential for reducing the disease burden in regions exhibiting substantial disparities. Countries like Italy and Japan, which show large effective differences between their actual disease burden and the frontier of optimal disease management, highlight critical opportunities where targeted health interventions could yield meaningful improvements. These findings reinforce the importance of implementing more equitable healthcare policies aimed at narrowing the gap in PCOS burden between high- and low-SDI countries.

The ARIMA model applied in this study forecasts a steady increase in the burden of adolescent PCOS over the coming two decades. Projections for 2041 estimate an ASIR of 371.69 per 100,000, an ASPR of 1732.68 per 100,000, and a DALYs rate of 15.37 per 100,000. To contextualize these projections, we sought available PCOS data from 2022–2024 in alternative databases, including the WHO Global Health Observatory, OECD Health Statistics, and national surveillance reports. However, comprehensive, population-based estimates for this period are not currently publicly available outside the GBD framework, largely due to the typical 2–3 years lag in data aggregation and reporting by national health systems.[57,58] Notably, the increasing recognition of PCOS as a priority public health issue has also prompted forecasting efforts beyond academic research, including proprietary models developed by commercial and market research organizations for healthcare planning purposes. While these proprietary forecasts are not publicly

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accessible for independent validation, their existence underscores the growing demand for and translational value of PCOS burden projections. The anticipated rise in adolescent PCOS cases highlights the urgent need for preventive strategies, such as lifestyle modifications and early screening programs. Utilizing the ARIMA model's predictive capabilities can guide public health policy, enabling more effective resource allocation and intervention planning. Nevertheless, it is essential that these projections be paired with the development of tailored, region-specific approaches that address the root causes of PCOS, ultimately aiming to mitigate its long-term impact on adolescent health.

The strengths of this study lie in its comprehensive, global assessment of the adolescent PCOS burden from 1990 to 2021, utilizing data from the GBD 2021 study an authoritative and widely recognized source in global health research. The extensive cross-country dataset enables an in-depth examination of incidence, prevalence, and disease burden trends across diverse regions, countries, and SDI categories. This broad scope offers valuable insights into the rising prevalence of adolescent PCOS, providing crucial evidence for healthcare professionals and policymakers to better target interventions. Additionally, the application of advanced statistical approaches, such as the ARIMA model for forecasting future trends, equips the study with a forward-looking perspective, supporting informed public health planning and long-term strategy development. Several aspects of this study distinguish it from existing GBD-based PCOS literature. First, its exclusive focus on adolescents (10–19 years) addresses a significant research gap, as prior studies have predominantly concentrated on the entire reproductive-age female population (15–49 years), obscuring age-specific patterns critical for early intervention. Second, the novel application of health inequality analysis (SII and Concentration Index) and frontier analysis to adolescent PCOS reveals a widening gap between high- and low-SDI regions and identifies substantial unrealized improvement potential in countries like Italy and Japan—insights not captured by conventional trend analysis. Third, the identification of Southeast Asia as the fastest-growing region (EAPC >2.4%), provides actionable intelligence for regional health policymakers.

However, this study has several limitations. First, although the GBD 2021 study offers extensive data coverage, it depends on secondary data sources of varying quality across regions, which may result in underreporting or overreporting of the disease burden, especially in low-resource settings. Second, the reliance on model-based estimates, while methodologically robust, cannot fully account for all potential confounding factors such as individual-level risk factors or the impacts of recent healthcare system changes and policy interventions. Specifically, the GBD framework does not provide individual-level data on potential contributing factors such as diet, physical activity, genetic predisposition, or environmental exposures, which precludes direct assessment of their association with adolescent PCOS burden. This limitation highlights the need for future studies using primary data collection to investigate the etiological determinants of PCOS in this age group. Furthermore, the clinical heterogeneity of PCOS presents challenges; the GBD framework lacks symptom specificity and does not differentiate between PCOS subtypes, limiting the ability to capture the unique epidemiological patterns associated with these variations. This constraint hampers a more detailed understanding of regional and global disparities in PCOS burden, highlighting the need for further research focusing on the diverse clinical presentations of the disease. Finally, external validation of our ARIMA forecasts was not feasible due to the lack of publicly available, population-based PCOS estimates from 2022 onward outside the GBD framework. Future studies should revisit this validation when such data become available.

Looking ahead, future research should aim to address the gaps identified in this study by investigating the underlying determinants of adolescent PCOS burden, particularly in low- and middle-SDI regions. As noted above, the GBD database cannot capture individual-level risk factors; therefore, more granular, population-based studies examining individual risk factors such as diet, physical activity, and genetic predispositions are essential for developing targeted interventions. Longitudinal cohort studies that follow adolescents over time will provide critical insights into the long-term health outcomes of PCOS, including risks for metabolic syndrome, type 2 diabetes, and cardiovascular disease. Furthermore, research focused on strengthening healthcare infrastructure and improving access in low-SDI countries is necessary to reduce diagnostic delays and underreporting, ensuring more accurate estimates of disease burden. Finally, policy-oriented studies evaluating the effectiveness of public health initiatives for PCOS prevention and management are vital for guiding evidence-based strategies to curb the rising burden among adolescents globally.

In conclusion, this study offers a comprehensive analysis of the global burden of adolescent PCOS, highlighting significant regional variations and socio-demographic disparities. The findings emphasize the critical need for early diagnosis, targeted public health interventions, and lifestyle modification strategies especially in middle- and low-SDI countries experiencing rapid increases in PCOS prevalence to effectively curb the rising disease burden. The evidence further underscores the necessity for tailored healthcare strategies that account for socio-economic and cultural factors, as exemplified by the experiences of countries like Italy and Japan. Moving forward, addressing gaps in healthcare access, enhancing awareness, and promoting healthy lifestyle behaviors will be pivotal in mitigating the long-term health consequences of PCOS especially in regions with a high disease burden. This study's findings offer crucial insights into the global epidemiology of adolescent PCOS and emphasize the importance of comprehensive, context-specific approaches to effectively tackle this growing public health challenge.

Conclusion

This study demonstrates a steady global increase in the incidence, prevalence, and DALYs of adolescent PCOS from 1990 to 2021, with notable regional disparities. Southeast Asia experienced the fastest rise in disease burden, whereas Western Europe sustained a higher yet relatively stable burden. Health inequality analyses reveal that low- and middle-SDI regions face more rapid increases, underscoring the urgent need for targeted public health interventions. Forecasts generated by the ARIMA model suggest that the adolescent PCOS burden is expected to rise over the forthcoming twenty years, underscoring the need for proactive measures to tackle this growing public health concern. Overall, this study offers valuable insights to inform public health policies aimed at mitigating the global impact of adolescent PCOS.

Abbreviations

AIC, Akaike Information Criterion; AMH, Anti-Müllerian Hormone; ARIMA, Autoregressive Integrated Moving Average; ASIR, Age-Standardized Incidence Rate; ASPR, Age-Standardized Prevalence Rate; ASR, Age-Standardized Rate; ASDR, Age-Standardized DALYs Rate; BIC, Bayesian Information Criterion; CI, Confidence Interval; CODEm, Cause of Death Ensemble Model; DALYs, Disability-Adjusted Life Years; EAPC, Estimated Annual Percentage Change; GBD, Global Burden of Disease; PCOM, Polycystic Ovary Morphology; PCOS, Polycystic Ovary Syndrome; SII, Slope Index of Inequality; SDI, Socio-Demographic Index; UI, Uncertainty Interval.

Data Sharing Statement

The original contributions of this study are included within the article and its supplementary materials. For further inquiries, please contact the corresponding author.

Ethical Approval Statement and Consent to Participate

The institutional ethics committee of Meizhou People's Hospital granted an exemption for this study, as it did not require formal approval due to the use of publicly available data from the 2021 GBD study. This research adhered to guidelines for accurate and transparent health assessment reporting. Given that all data were publicly accessible, ethical approval and informed consent were not required.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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The authors declare that they have no competing interests in this work.

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