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Epidemiological and demographic drivers of alcohol-attributable pancreatitis from 1990 to 2021: Findings from the 2021 Global Burden of Disease study

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ABSTRACT

Background: Alcohol significantly contributes to pancreatitis, causing high global mortality and health burden. This study examines trends in alcohol-attributable pancreatitis (AAP) from 1990 to 2021 using Global Burden of Disease (GBD) 2021 data, focusing on demographic, temporal, and regional variations to inform policymaking.
Methods: AAP-related deaths and disability-adjusted life years (DALYs) were analyzed across 204 countries from 1990 to 2021, stratified by Sociodemographic Index (SDI), gender, and age groups. An age-period-cohort model assessed age-standardized DALY rates (ASDR), and decomposition analysis quantified impacts of population growth, aging, and epidemiological changes.
Results: AAP-related DALYs rose from 401,700 in 1990 to 699,300 in 2021, though ASDR and ASMR showed declines globally. Burden increased notably in low and lower-middle SDI regions, especially among those under 40, while high SDI regions achieved better control. Males faced a disproportionately high burden due to alcohol consumption patterns, although some regions saw rising female burdens. Low-SDI areas suffered from limited healthcare, increasing alcohol use, and weak policies, with younger populations contributing significantly to rising burdens. Projections estimate 1.146 million DALYs annually by 2050, with males comprising over 90%. A GBD-AAP visualization platform was developed to present burden data and trends.
Conclusions: AAP exhibits significant regional and gender disparities. Targeted measures, including alcohol regulation, resource allocation, and public health education, are critical in low-SDI regions and among young males to mitigate AAP burden. The GBD-AAP platform offers valuable tool for targeted interventions.

Introduction

Alcohol has been shown to be toxic to numerous parts of the body, including the central and peripheral nervous systems, heart, bone marrow, liver, and pancreas (Corrao, Vincenzo Bagnardi, Zambon, & Carlo La, 2004). In 2022, the WHO released the Global Action Plan on Alcohol 2022–2030, which aims to reduce the health risks associated with the harmful use of alcohol through the implementation of effective evidence-based strategies (Organization, 2024). Alcohol exposure is a well-established cause of pancreatitis. Epidemiological studies have identified excessive alcohol consumption as the second leading cause of pancreatitis after gallstones (Chris & Santhi Swaroop Vege, 2016), accounting for 50%–80% of all cases, with regional variations in prevalence (Żorniak et al., 2019). Additionally, heavy alcohol use increases the risk of recurrent acute pancreatitis and contributes to its progression to chronic pancreatitis (Usama Ahmed Ali et al., 2016; Sara Bertilsson, Per, & Evangelos, 2015). Pancreatitis, an inflammatory condition of the pancreas, is associated with high global mortality and significant healthcare burdens (Lankisch et al., 2015; Yadav et al., 2013).

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Alcohol-induced pancreatitis exhibits notable population-specific characteristics, with its impact varying significantly across different groups. While increases in pancreatitis-related mortality have been observed in certain countries, this trend is not universally consistent worldwide (Ramstedt, 2004; O'Farrell, Allwright, Toomey, Bedford, & Conlon, 2007; Sand et al., 2009). As Żorniak et al. noted, although alcohol exerts direct toxic effects on pancreatic tissue, only a small proportion of drinkers develop pancreatitis, suggesting that genetic and environmental factors likely play an important role (Żorniak, Simon, Mayerle, & Beyer, 2020). Additionally, Pelli et al. found that individuals under 45 years of age experiencing their first episode of alcohol-related acute pancreatitis are more likely to suffer from recurrent pancreatitis, indicating that younger populations may be more vulnerable to alcohol-induced pancreatic damage (Pelli, Sand, & Laippala, 2000). Similarly, Chen et al.'s study in Taiwan revealed that alcohol-induced pancreatitis predominantly affects males and is closely associated with increased severity and higher recurrence risk (Chen, Chia-Yen, Nai-Jen, Chen, & Wan-Long, 2006). Therefore, systematically evaluating the burden of alcohol-induced pancreatitis across different regions and age groups is essential to understanding its trends and developing targeted intervention strategies.

This study utilized data from GBD 2021 to analyze the distribution and temporal trends of the burden of alcohol-attributable pancreatitis (AAP) across various regions, populations, and time periods based on burden measures. It also identified region-specific risk factors. These findings offer valuable insights for optimizing healthcare resource allocation and informing policy development.

Materials and methods

Data sources

This study analyzed the dataset from the 2021 Global Burden of Disease (GBD) study, which is publicly available through the Global Health Data Exchange (GHDx) website (https://ghdx.healthdata.org). Since 1990, the GBD study has continuously refined its methods to estimate mortality and health losses from various diseases, generating updates every 2–3 years to maintain accuracy and relevance (Zhenqiu et al., 2019; Population-level risks of alcohol consumption, 2022). GBD 2021 provides the most up-to-date dataset on the global burden of AAP from 1990 to 2021 across 204 countries and regions. Compared to previous cycles, this iteration incorporates newly available data sources and methodological improvements to enhance the reliability of estimates (Zi et al., 2024). In summary, the GBD database includes diverse primary data sources, such as surveys, censuses, and other health-related datasets. Mortality data were estimated using the Cause of Death Ensemble Model (CODEm), a statistical modeling framework designed to capture cause-specific mortality trends (Global age, 2020). DALYs (disability-adjusted life years) were calculated as the sum of years of life lost (YLL) due to premature mortality and years lived with disability (YLD) for each age, sex, and location (Measuring universal health coverage based, 2020). Mortality rates and DALYs were derived from the mean of 1000 draws, with 95% uncertainty intervals (UI) calculated to account for variations in disease burden estimates. The UI accounts not only for parameter estimation variance but also for uncertainties in the data collection process and model selection.

Data analysis

For the data analysis, the GBD 2021 study categorized the world into 21 regions based on epidemiological similarities and geographic proximity. Additionally, the SDI, a composite indicator of sociodemographic conditions influencing health outcomes, was used to classify countries and regions into quintiles (high, high-middle, middle, low-middle, and low development levels).

Age-standardized rates (ASR), the number and proportion of deaths, and DALYs were extracted from GBD 2021. The estimated annual percentage change (EAPC) in age-standardized mortality rates (ASMR) and age-standardized DALY rates (ASDR) was calculated using a generalized linear model with Gaussian distribution to assess temporal trends in AAP. A higher EAPC indicates a greater disease burden due to AAP. If both the EAPC and the lower bound of its 95% confidence interval (CI) are greater than 0, the disease burden is increasing; otherwise, a declining trend is indicated.

Using decomposition analysis at the regional level, hierarchical cluster analysis was applied to group patterns of demographic and epidemiological drivers of AAP DALYs from 1990 to 2021. This approach assessed the contributions of population growth, aging, and epidemiological changes to ASDR across SDI regions. Spearman correlation analysis was then used to evaluate the relationship between ASDR and SDI.

Frontier analysis identified leading countries or regions, which achieved the lowest AAP burden at their respective SDI levels. The gap between a country or region's observed burden and its potential burden under its SDI is referred to as the "efficiency gap." This gap indicates how much of the burden could be reduced through better utilization of available sociodemographic resources (Yan et al., 2018).

Data analysis and visualizations were conducted using R software (version 4.4.2). The R packages used included "BAPC" (Riebler & Held, 2017), "factoextra" (Kassambara et al., 2020), "tidyverse" (Wickham et al., 2019), "ggplot2" (Wickham, 2016) and "stats" (Team, 2023). A p-value of less than 0.05 was considered statistically significant.

GBD-AAP platform development

Considering the variations in disease burden and trends across countries and regions, this study developed the GBD-AAP platform using the Shiny package (Chang, Cheng, Schloerke, & Xie, 2024). The platform enables visualization of disease burden and future trends for 204 countries and regions, allowing users to customize their selection of locations and evaluation metrics.

Results

Global DALYs and mortality estimates for AAP

In 2021, approximately 16% of the DALYs associated with all pancreatitis cases were attributable to alcohol. The number of DALYs increased by 74.09%, rising from 401,700 in 1990 to 699,300 in 2021, nearly doubling over three decades. However, despite the increase in absolute numbers, the age-standardized rate per 100,000 population declined from 8.88 (6.25–12.04) in 1990 to 8.22 (5.72–10.86) in 2021. This suggests that while the overall population growth contributed to the rise in the absolute burden, the relative rate showed a downward trend. The estimated EAPC was −0.317 (−0.537 to −0.096), indicating a declining trend in the global DALYs burden of AAP, consistent with the decrease in the relative rate (Table 1). Similarly, 15% of the global mortality burden from all pancreatitis cases was attributable to alcohol in 2021. Over the past 30 years, the number of deaths caused by AAP increased by 88.02%. However, the EAPC for AAP-related deaths from 1990 to 2021 was calculated as −0.269 (−0.46 to −0.077), highlighting a decreasing trend in the global mortality burden attributable to AAP (Table 2).

Table 1
Global AAP-related DALYs burden table in 1990–2021.

Location	1990			2021			EAPC(%)
	Number	ASDR (/10^6)	Percent (%)	Number	ASDR (/10^6)	Percent (%)	
Global	401,671.32 (280,352.07,543,581.55)	8.88 (6.25,12.04)	0.16 (0.11,0.21)	699,335.04 (486,293.01,924,031.99)	8.22 (5.72,10.86)	0.17 (0.12,0.22)	−0.317 (−0.537,−0.096)
High SDI	105,279.22 (76,181.43,137,281.6)	10.29 (7.45,13.42)	0.25 (0.18,0.32)	123,550.06 (85,940.38,165,401.01)	7.81 (5.51,10.27)	0.25 (0.18,0.32)	−1.005 (−1.131,−0.878)
High-middle SDI	168,384.71 (121,086.91,223,703.72)	15.87 (11.43,21.08)	0.23 (0.16,0.29)	251,721.93 (179,902.73,335,940.24)	14.67 (10.44,19.43)	0.23 (0.17,0.3)	−0.484 (−0.992,0.026)
Middle SDI	75,787.96 (48,713.62,108,007.14)	5.41 (3.47,7.78)	0.12 (0.08,0.16)	167,046.39 (115,483.75,220,626.33)	6.04 (4.19,7.97)	0.16 (0.11,0.2)	0.488 (0.357,0.619)
Low-middle SDI	37,546.82 (19,099.05,62,741.23)	4.46 (2.33,7.46)	0.06 (0.03,0.09)	111,718.11 (70,375.85,154,954.43)	6.29 (3.94,8.8)	0.11 (0.07,0.15)	1.55 (1.324,1.776)
Low SDI	13,867.01 (6506.13,24,872.78)	4.45 (2.11,7.72)	0.06 (0.03,0.1)	44,400.24 (25,590.11,70,884.6)	5.97 (3.44,9.47)	0.10 (0.06,0.15)	1.18 (0.972,1.388)
High-income Asia Pacific	14,414.69 (9355.15,19,958.12)	7.15 (4.64,9.92)	0.23 (0.15,0.31)	11,139.67 (7002.21,15,962.18)	3.75 (2.41,5.38)	0.22 (0.15,0.3)	−2.452 (−2.622,−2.282)
High-income North America	23,034.51 (16,050.8,31,514.45)	7.22 (5.04,9.89)	0.21 (0.14,0.27)	37,078.47 (23,916.67,51,449.37)	7.46 (4.95,10.29)	0.23 (0.16,0.3)	0.192 (0.001,0.384)
Caribbean	2131.29 (1328.29,2991.58)	7.10 (4.46,10.01)	0.15 (0.1,0.21)	3524.06 (2267.28,5121.86)	6.82 (4.39,9.9)	0.16 (0.11,0.23)	−0.016 (−0.159,0.128)
Andean Latin America	3771.09 (1865.61,5788.44)	13.50 (6.97,20.68)	0.12 (0.06,0.18)	7404.49 (4338.62,10,793.83)	11.32 (6.61,16.46)	0.16 (0.09,0.22)	−0.433 (−0.626,−0.24)
Tropical Latin America	17,843.03 (12,622.23,23,988.51)	14.17 (9.88,19.28)	0.17 (0.12,0.24)	36,126.77 (24,746.33,49,177.91)	13.82 (9.48,18.81)	0.18 (0.13,0.24)	0.093 (−0.255,0.441)
Central Latin America	14,114.38 (9955.92,18,763.85)	11.57 (8.22,15.36)	0.17 (0.12,0.22)	30,601.90 (21,039.68,41,865.7)	11.47 (7.87,15.69)	0.17 (0.12,0.23)	−0.225 (−0.514,0.066)
Southern Latin America	11,088.74 (7959.66,14,354.44)	23.48 (16.83,30.47)	0.27 (0.19,0.34)	9093.92 (6022.68,12,540.33)	11.29 (7.5,15.61)	0.21 (0.14,0.28)	−1.87 (−2.177,−1.563)
Western Europe	63,947.08 (46,291.13,81,054.21)	12.97 (9.55,16.28)	0.30 (0.23,0.38)	57,699.82 (40,009.8,76,620.4)	8.07 (5.72,10.55)	0.27 (0.19,0.36)	−1.603 (−1.699,−1.506)
Central Europe	40,761.94 (28,795.04,52,294.83)	28.87 (20.52,36.94)	0.26 (0.19,0.33)	44,452.64 (32,155.76,56,844.34)	27.25 (20.11,34.73)	0.30 (0.22,0.38)	−0.496 (−0.725,−0.267)
Eastern Europe	92,294.97 (65,457.79,127,057.05)	35.77 (25.42,49.06)	0.25 (0.18,0.33)	172,784.73 (124,114.94,228,415.87)	64.03 (46.21,84.35)	0.27 (0.2,0.34)	1.502 (0.648,2.362)
Central Asia	8372.98 (5202.05,11,751.12)	15.21 (9.28,21.53)	0.18 (0.11,0.25)	13,675.75 (8901.74,18,939.54)	13.82 (8.97,19.12)	0.18 (0.12,0.24)	−0.98 (−1.29,−0.669)
North Africa and Middle East	1011.96 (565.82,1582.79)	0.46 (0.25,0.73)	0.02 (0.01,0.03)	2003.29 (1172.27,2993.95)	0.36 (0.21,0.55)	0.02 (0.01,0.03)	−0.89 (−1.012,−0.768)
South Asia	33,316.01 (14,524.98,60,398.74)	4.03 (1.8,7.28)	0.05 (0.02,0.08)	97,271.35 (56,719.04,140,892.03)	5.42 (3.16,7.89)	0.09 (0.06,0.14)	1.555 (1.205,1.905)
Southeast Asia	11,512.13 (6426.85,18,402.05)	3.19 (1.78,5.1)	0.06 (0.03,0.08)	41,232.82 (25,818.48,63,715.2)	5.49 (3.43,8.48)	0.12 (0.08,0.16)	1.976 (1.868,2.084)
East Asia	38,692.76 (23,581.73,56,720.47)	3.61 (2.17,5.32)	0.12 (0.07,0.18)	60,082.90 (36,857.3,90,978.81)	3.02 (1.87,4.56)	0.16 (0.11,0.22)	−0.47 (−0.745,−0.194)
Australasia	1736.65 (1223.5,2318.98)	7.64 (5.43,10.16)	0.28 (0.21,0.36)	2436.49 (1669.69,3268.66)	5.38 (3.78,7.11)	0.27 (0.19,0.35)	−0.886 (−1.117,−0.654)
Oceania	113.32 (42.77,228.57)	2.19 (0.82,4.41)	0.07 (0.04,0.11)	182.26 (77.79,346.87)	1.49 (0.63,2.79)	0.06 (0.03,0.09)	−1.179 (−1.466,−0.891)
Western Sub-Saharan Africa	14,856.94 (7826.06,25,967.61)	12.84 (6.88,22.08)	0.12 (0.07,0.18)	48,541.29 (30,471.14,71,775.44)	16.16 (10.23,23.61)	0.15 (0.11,0.2)	0.714 (0.655,0.773)
Eastern Sub–Saharan Africa	4247.82 (1765.63,7778.16)	4.04 (1.74,7.34)	0.11 (0.06,0.16)	13,784.63 (6639.07,23,292.3)	5.21 (2.6,8.6)	0.14 (0.09,0.2)	0.846 (0.698,0.995)
Central Sub-Saharan Africa	1185.19 (413.42,2544.65)	3.58 (1.21,7.55)	0.10 (0.04,0.17)	3969.67 (1812.91,7481.1)	4.41 (2.04,7.88)	0.12 (0.06,0.19)	1.571 (0.671,2.48)
Southern Sub-Saharan Africa	3223.84 (1989.27,4706.8)	8.54 (5.21,12.73)	0.24 (0.17,0.31)	6248.11 (4160.2,8485.93)	8.29 (5.51,11.16)	0.23 (0.16,0.3)	−0.098 (−0.242,0.046)

Table 2
Evolution table of the global AAP−related deaths burden in 1990−2021.

Location	1990			2021			EAPC(%)
	Number	ASMDR (/10^6)	Percent (%)	Number	ASMR (/10^6)	Percent (%)	
Global	9971.79 (6888.25,13,403.82)	0.24 (0.16,0.32)	0.14 (0.1,0.19)	18,749.03 (12,763.28,24,677.82)	0.22 (0.15,0.29)	0.15 (0.1,0.2)	−0.269 (−0.46,−0.077)
High SDI	3033.32 (2119.88,3998.38)	0.29 (0.2,0.38)	0.22 (0.16,0.29)	4085.43 (2712.54,5502.75)	0.22 (0.15,0.29)	0.23 (0.16,0.3)	−0.922 (−1.066,−0.777)
High-middle SDI	3952.61 (2787.05,5163.82)	0.39 (0.27,0.51)	0.20 (0.15,0.27)	6506.76 (4581.97,8559.82)	0.36 (0.26,0.47)	0.20 (0.14,0.26)	−0.423 (−0.867,0.022)
Middle SDI	1748.85 (1114.8,2506.61)	0.14 (0.09,0.2)	0.10 (0.06,0.13)	4343.04 (2846.11,5783.77)	0.16 (0.1,0.21)	0.13 (0.09,0.17)	0.613 (0.48,0.745)
Low-middle SDI	879.34 (444.17,1471.55)	0.12 (0.06,0.19)	0.05 (0.03,0.08)	2725.42 (1680.21,3898.78)	0.16 (0.1,0.24)	0.09 (0.06,0.13)	1.605 (1.369,1.842)
Low SDI	336.81 (157.62,585.03)	0.12 (0.06,0.21)	0.06 (0.03,0.09)	1061.72 (607.57,1684.83)	0.16 (0.1,0.26)	0.09 (0.06,0.13)	1.209 (0.997,1.421)
High-income Asia Pacific	362.56 (222.17,492.7)	0.18 (0.11,0.25)	0.20 (0.13,0.27)	352.76 (208.69,501.62)	0.09 (0.05,0.12)	0.19 (0.12,0.26)	−2.96 (−3.146,−2.773)
High-income North America	585.73 (390.68,819.15)	0.18 (0.12,0.24)	0.18 (0.12,0.24)	1116.22 (686.57,1557.12)	0.20 (0.13,0.27)	0.20 (0.13,0.28)	0.467 (0.213,0.722)
Caribbean	51.10 (31.88,72.19)	0.18 (0.11,0.26)	0.13 (0.08,0.19)	91.39 (54.35,131.23)	0.17 (0.1,0.25)	0.14 (0.09,0.2)	0.011 (−0.156,0.178)
Andean Latin America	89.79 (46.86,139.31)	0.36 (0.18,0.56)	0.11 (0.06,0.16)	198.14 (110.23,292.16)	0.32 (0.17,0.47)	0.13 (0.08,0.19)	−0.225 (−0.436,−0.014)
Tropical Latin America	401.97 (276.65,547.28)	0.35 (0.24,0.48)	0.15 (0.1,0.21)	957.88 (637.64,1297.54)	0.37 (0.24,0.5)	0.15 (0.1,0.21)	0.418 (0.04,0.798)
Central Latin America	312.85 (220.5411.63)	0.29 (0.2,0.38)	0.14 (0.1,0.19)	752.12 (486.7,1053.19)	0.29 (0.18,0.4)	0.14 (0.1,0.2)	−0.182 (−0.444,0.08)
Southern Latin America	339.34 (235.08,443.95)	0.73 (0.51,0.96)	0.25 (0.17,0.33)	298.45 (188.62,425.41)	0.35 (0.23,0.5)	0.19 (0.12,0.26)	−1.812 (−2.102,−1.521)
Western Europe	2209.67 (1565.66,2870.75)	0.41 (0.29,0.53)	0.27 (0.2,0.35)	2343.24 (1540.15,3172.73)	0.26 (0.18,0.35)	0.25 (0.17,0.33)	−1.429 (−1.526,−1.333)
Central Europe	1041.46 (714.35,1346.16)	0.73 (0.5,0.94)	0.23 (0.16,0.3)	1341.60 (945.32,1745.7)	0.73 (0.53,0.94)	0.26 (0.19,0.34)	−0.224 (−0.469,0.022)
Eastern Europe	1744.85 (1237.39,2265.95)	0.66 (0.48,0.86)	0.23 (0.17,0.3)	3868.69 (2756.17,5101.41)	1.35 (0.98,1.78)	0.24 (0.18,0.31)	1.906 (1.05,2.77)
Central Asia	192.17 (115.05,274.35)	0.37 (0.22,0.53)	0.16 (0.1,0.22)	308.27 (201,440.18)	0.33 (0.21,0.47)	0.16 (0.1,0.21)	−1.074 (−1.388,−0.758)
North Africa and Middle East	23.72 (12.4,38.16)	0.01 (0.01,0.02)	0.02 (0.01,0.02)	51.09 (26.6,80.88)	0.01 (0.01,0.02)	0.01 (0.01,0.02)	−0.71 (−0.832,−0.587)
South Asia	767.50 (342.61,1394.36)	0.10 (0.04,0.19)	0.04 (0.02,0.07)	2376.16 (1355.6,3514.75)	0.14 (0.08,0.21)	0.08 (0.05,0.12)	1.659 (1.282,2.037)
Southeast Asia	263.03 (146.37,425.65)	0.08 (0.04,0.13)	0.04 (0.03,0.06)	1032.36 (629.69,1618.33)	0.15 (0.09,0.23)	0.09 (0.06,0.13)	2.126 (2.001,2.252)
East Asia	950.46 (542.9,1417.08)	0.10 (0.06,0.15)	0.10 (0.06,0.15)	1823.70 (1072.84,2814.59)	0.09 (0.05,0.14)	0.14 (0.09,0.19)	−0.223 (−0.462,0.017)
Australasia	57.06 (37.31,78.31)	0.25 (0.16,0.34)	0.25 (0.16,0.34)	93.45 (59.4131.39)	0.18 (0.12,0.25)	0.24 (0.16,0.32)	−0.83 (−1.074,−0.585)
Oceania	2.24 (0.82,4.6)	0.05 (0.02,0.1)	0.06 (0.03,0.09)	3.71 (1.52,7.13)	0.03 (0.01,0.06)	0.05 (0.03,0.08)	−1.107 (−1.375,−0.838)
Western Sub-Saharan Africa	370.87 (198.93,632.55)	0.36 (0.19,0.6)	0.11 (0.07,0.17)	1175.84 (739.52,1714.22)	0.45 (0.28,0.65)	0.14 (0.1,0.19)	0.763 (0.706,0.819)
Eastern Sub-Saharan Africa	104.75 (44.38,192.42)	0.12 (0.05,0.22)	0.10 (0.06,0.15)	326.00 (162.84,543.28)	0.15 (0.07,0.24)	0.13 (0.08,0.19)	0.754 (0.602,0.906)
Central Sub-Saharan Africa	28.17 (9.32,59.92)	0.10 (0.03,0.21)	0.09 (0.04,0.16)	90.48 (42.06,164.92)	0.12 (0.05,0.22)	0.12 (0.06,0.18)	1.454 (0.516,2.4)
Southern Sub-Saharan Africa	72.52 (42.79,111.32)	0.22 (0.12,0.34)	0.22 (0.16,0.29)	147.49 (97.24,201.15)	0.21 (0.14,0.29)	0.21 (0.14,0.28)	−0.013 (−0.119,0.093)

Regional burden of AAP

Interestingly, while the global burden of AAP, measured in terms of DALYs and mortality, has generally decreased over time, significant regional variations persist. In particular, Low-middle SDI, Low SDI, and Middle SDI regions continue to experience increasing burdens, as indicated by EAPC results. The ASDR of AAP rose in regions such as Middle SDI (0.488 [0.357, 0.619]), Low-middle SDI (1.55 [1.324, 1.776]), and Low SDI (1.18 [0.972, 1.388]), while the ASDR also showed increases in the same regions (Middle SDI: 0.613 [0.48, 0.745]; Low-middle SDI: 1.605 [1.369, 1.842]; Low SDI: 1.209 [0.997, 1.421]) (Tables 1 and 2).

Regions such as High-income North America and Tropical Latin America also showed notable burdens. As shown in Fig. 1A and B, global ASDRs of AAP in 2021 displayed significant variability, with the top 10 regions dominated by male populations. These regions include Russian Federation (ASDR: 133.67 [99.29, 174.38]), Republic of Moldova (120.47 [87.18, 157.74]), Latvia (116.94 [86.95, 150.17]), Lithuania (105.31 [77.43, 135.49]), Ukraine (93.83 [56.08, 139.89]), Belarus (91.10 [65.59, 123.15]), Romania (73.94 [54.3, 97.34]), Estonia (65.86 [47.29, 88.23]), Poland (64.41 [48.47, 81.59]), and Kazakhstan (62.95 [39.83, 94.83]) (Fig. 1C).

However, among regions with the fastest-growing burdens, the increase among females cannot be overlooked. For example, significant EAPCs were observed in Iran (Islamic Republic of) (41.23 [33.94, 48.91]), Viet Nam (16.50 [14.85, 18.19]), Libya (14.44 [10.19, 18.85]), Cook Islands (10.50 [9.53, 11.47]), and Nepal (10.25 [8.96, 11.55]) (Fig. 1D). This means that while regions like the Russian Federation and Republic of Moldova have high male ASDRs, their growth trends are relatively low, with Republic of Moldova even exhibiting a declining trend. By comparison, regions such as Viet Nam, Iran, and Myanmar for males, and Iran (Islamic Republic of) for females, have low ASDRs but significantly higher EAPCs (Fig. 1E). If left unaddressed, these regions are likely to see a substantial increase in future burdens.

Burden of disease across age groups

For AAP, the ASDR increases with age, with males contributing disproportionately higher burdens compared to females (Fig. 2A).

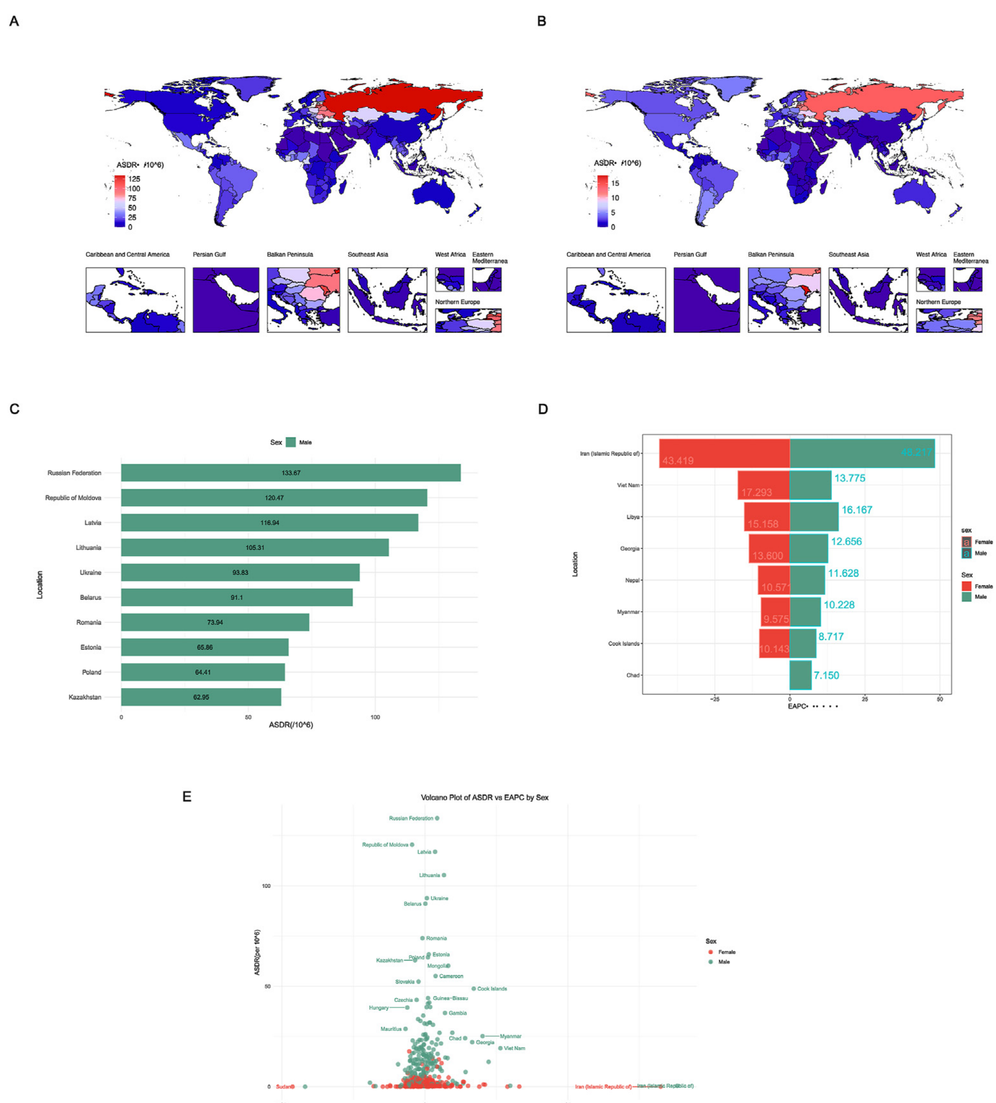

Fig. 1. Distribution of ASDR and EAPC in AAP globally A. Distribution of ASDR in males globally B. Distribution of ASDR in females globally C. Top 10 populations in terms of ASDR D. Top 15 populations in terms of EAPC E. Mapping of ASDR and EAPC in different regions for different gender populations (Note: ASDR = Assessed age-Standardized DALY Rates).

Globally, the burden among females has been effectively controlled, but the ASDR among males, particularly young males under 40, has shown an increasing trend (Fig. 2B). A more nuanced analysis reveals noteworthy regional variations. In High SDI regions, ASDR has decreased across all age groups. However, in High-middle and Middle SDI regions, a reversal of this trend is evident, particularly among younger populations. In contrast, Low-middle and Low SDI regions have experienced an increase in ASDR across all age groups (Fig. 2C).

Impact of age, period, and cohort (APC) on ASDR

The APC model, stratified by SDI quintiles, was used to evaluate the age, period, and cohort effects. The age effect, represented by the longitudinal age curve, illustrates the natural history of ASR. The period effect reflects the relative risk of occurrence over time, enabling trends to be tracked. Meanwhile, the cohort effect characterizes relative risks based on birth cohorts, highlighting incidence variations over time. Overall, the age, period, and cohort effects demonstrated consistent trends globally and across SDI regions.

The period-cohort model revealed that over the past three decades, ASDR trends in different SDI regions were aligned with global patterns, showing a decrease followed by an increase and then another decrease in males, while females exhibited a consistent downward trend (Fig. 3A). The age-cohort model (Fig. 3B) further showed that among females, ASDR increased with age, whereas trends among males were more irregular. Notably, in High SDI and High-middle SDI regions, ASDR reached its lowest levels in the most recent period (2017–2021). Conversely, in Middle SDI, Low-middle SDI, and Low SDI regions, ASDR peaked during the same period, illustrating that while high SDI regions have effectively controlled ASDR, the burden has continued growing in lower SDI regions, even exacerbating over time.

Correlation analysis between SDI and ASDR

To further examine the relationship between SDI and ASDR, a Spearman correlation analysis was conducted. At the global level, SDI and ASDR were positively correlated (cor = 0.353, P = 0.000 < 0.05). However, as shown in Fig. 4, a non-linear

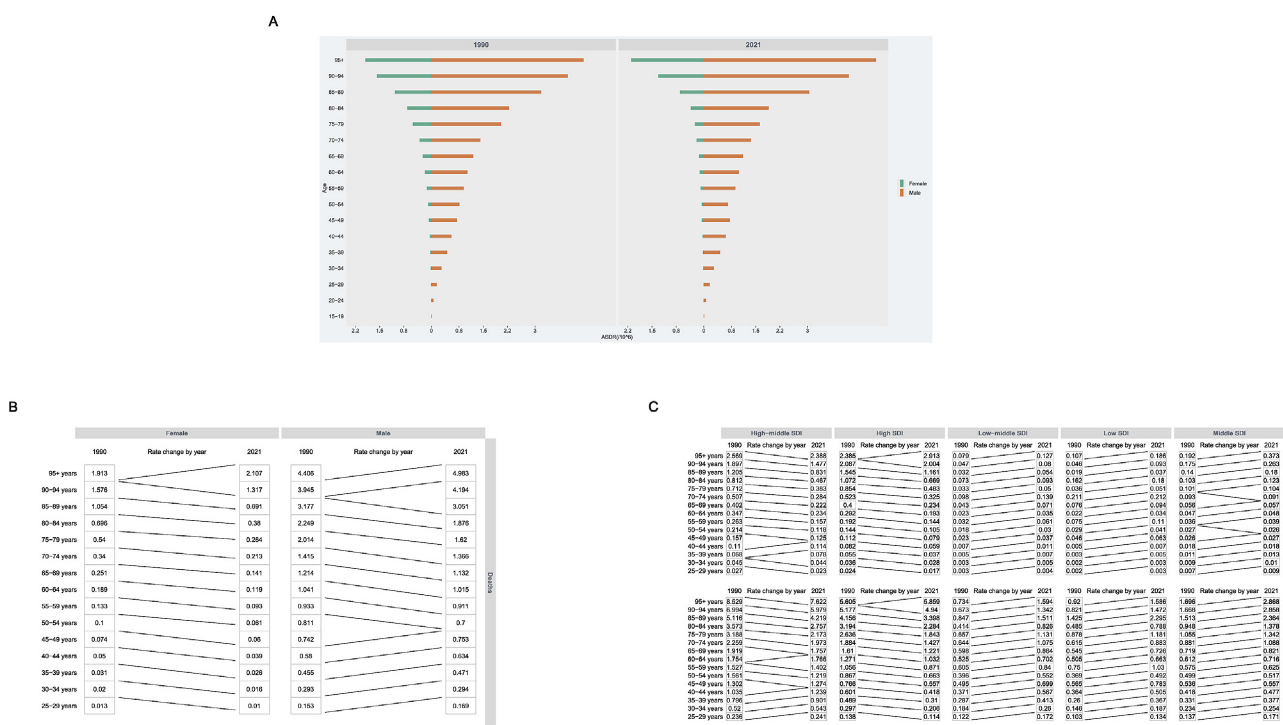

Fig. 2. Global Distribution of ASDR by Age A. Number of ASDR Burden by Age B. Trends in ASDR by Gender by Age C. Trends in ASDR by Gender by Age in Different SDI Regions (Note: SDI = Sociodemographic Index).

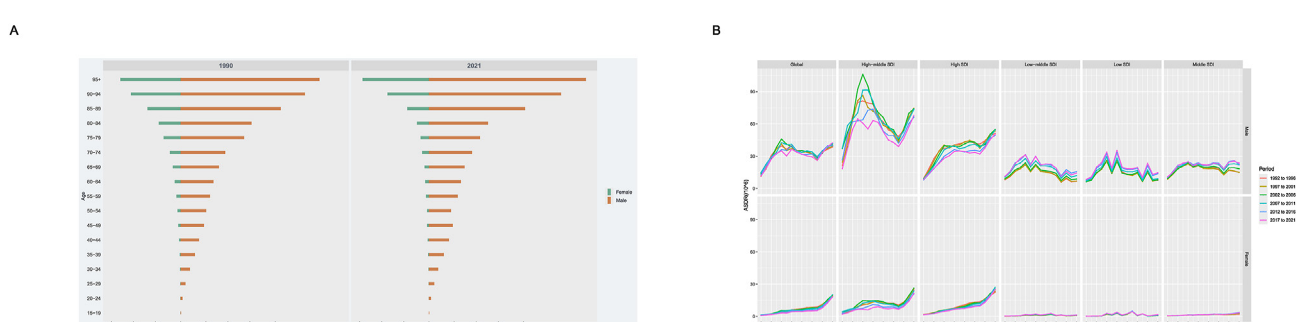

Fig. 3. APC model A. Period-cohort effect B. Age-period effect.

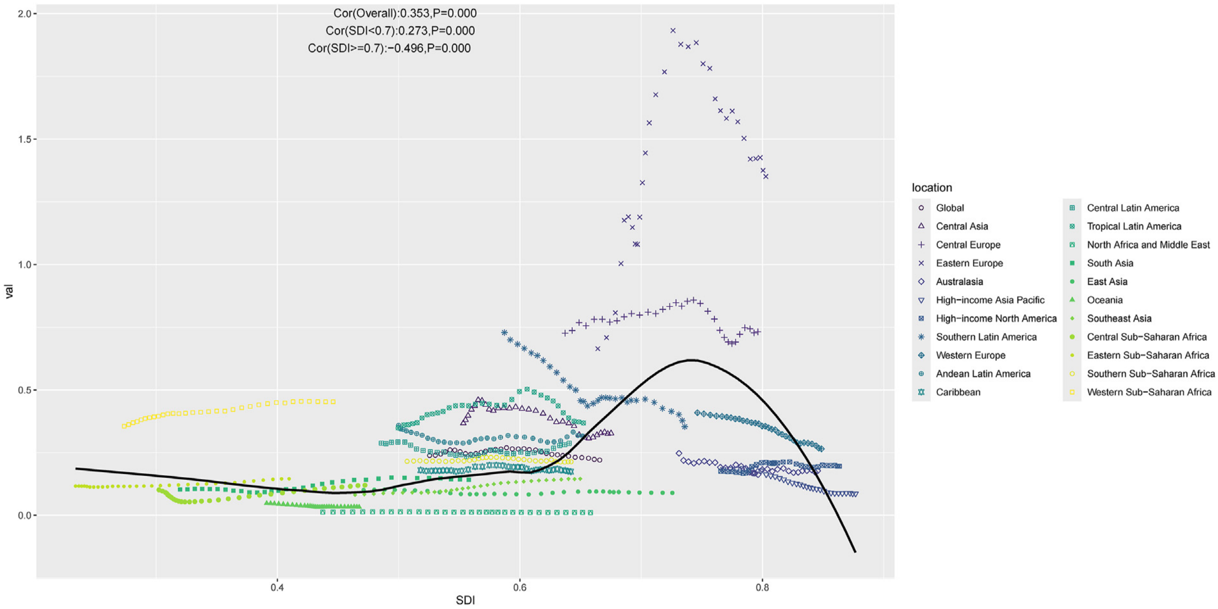

Fig. 4. Correlation between ASDR and SDI (Note: Folding table fitting line).

relationship between these variables was observed. Using SDI = 0.7 as the cutoff, a positive correlation was found when SDI <0.7 (cor = 0.273, P = 0.000 < 0.05), whereas a negative correlation was identified when SDI ≥0.7 (cor = −0.496, P = 0.000 < 0.05).

Frontier analysis

Overall, as SDI increases, the efficiency gap initially widens and then narrows, suggesting that high-SDI regions have achieved stable control over ASDR. In contrast, middle- and low-SDI regions require enhanced control measures (Fig. 5A). The 10 countries with the largest efficiency gaps compared to the frontier (efficiency gap: 49.09 [37.39, 60.98]) include the Russian Federation, Republic of Moldova, Latvia, Lithuania, Ukraine, Belarus, Romania, Estonia, Poland, and Kazakhstan (ASDR range: 32.76–69.92). At comparable SDI levels, these countries exhibit significantly higher ASDRs than others (Fig. 5B).

Decomposition analysis

Globally, population growth is the primary driver of ASDR, followed by epidemiological changes and aging. This trend is generally consistent across different SDI regions (Fig. 6).

BAPC projection

Finally, we utilized BAPC to project the global burden and ASDR of AAP from 2022 to 2050, including a gender-specific subgroup analysis. By 2050, the global burden is estimated to reach 1.146 million cases, with males accounting for the majority (approximately 1.053 million) and females for 93,100 (Fig. 7). Globally, ASDR shows a declining trend, with a slower reduction observed among females.

Shiny platform construction

Utilizing the Shiny platform, we developed GBD-AAP, a tool for visualizing the disease burden and forecasting results of 204 countries and regions, accessible at http://116.196.73.86:3838/GBD-AAP/ free of charge. Using China as a case study, this research applied the GBD-AAP platform to analyze the specific burden and associated trends. In 2021, China's burden was estimated at 55,235 (34,132 to 83,162), marking an increase from 2019's 34,456.64 (20,826 to 51,053). However, the computed EAPC (−0.33 [−0.62 to −0.04]) indicates a declining trend in ASDR. It is notable that the downward trend for males was not statistically significant (EAPC: −0.20 [−0.48 to 0.08]), suggesting that further efforts are needed to control the AAP burden among men (Fig. 8A).

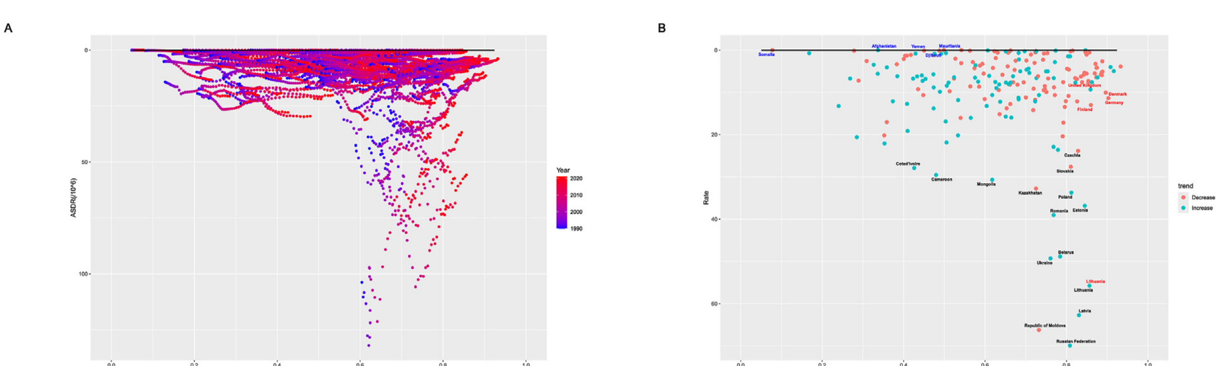

Fig. 5. Frontier analysis A. Year-by-year mapping of ASDR and SDI in different regions B. Mapping of SDI and ASDR changes in different regions.

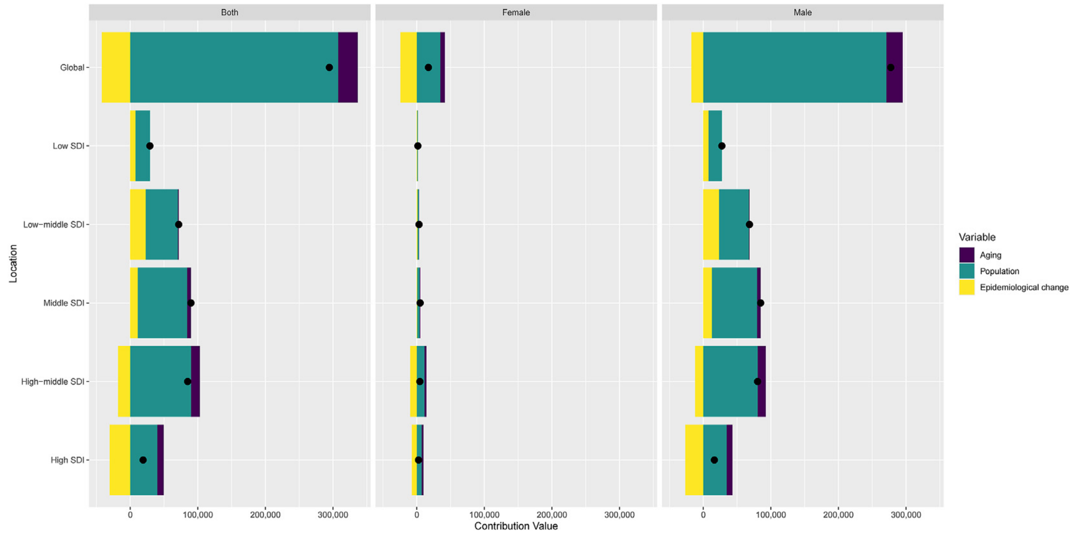

Fig. 6. Decomposition analysis in ASDR.

On a global scale, China's ranking improved significantly, moving from the top 9.44%–3.38%, highlighting effective national control. Specifically, the burden rank for females saw a slight decline from 9.83% to 9.87%, while males exhibited the most significant improvement, advancing from 9.87% to 4.24% (Fig. 8B).

Projections based on BAPC suggest that by 2050, the region's DALYs burden is expected to rise from 34,500 to 184,100, with males contributing approximately 164,800 and females 19,400 (Fig. 8C).

Discussion

Pancreatitis is an inflammatory condition of the pancreas, which can be classified into acute and chronic forms. Acute pancreatitis is often triggered by factors such as alcohol abuse and hyperlipidemia, and in severe cases, it can progress to pancreatic necrosis, leading to multi-organ failure. Additionally, recurrent episodes of acute pancreatitis or chronic alcohol consumption can result in chronic pancreatitis, causing significant physical suffering and a substantial burden on patients' lives. A comprehensive study assessing the global burden of pancreatitis revealed a rapid increase in the prevalence of the disease over the past three decades, with the number of deaths rising from approximately 68,490 in 1990 to 122,416 in 2021. The study also evaluated the impact of various factors and highlighted that reducing alcohol consumption is crucial for alleviating the future burden of pancreatitis (Li et al., 2024). Unfortunately, the specific distribution and disparities in the burden of AAP remain inadequately addressed and understudied. As the first comprehensive study on the burden of AAP, this research utilizes global data from GBD 2021 to characterize the

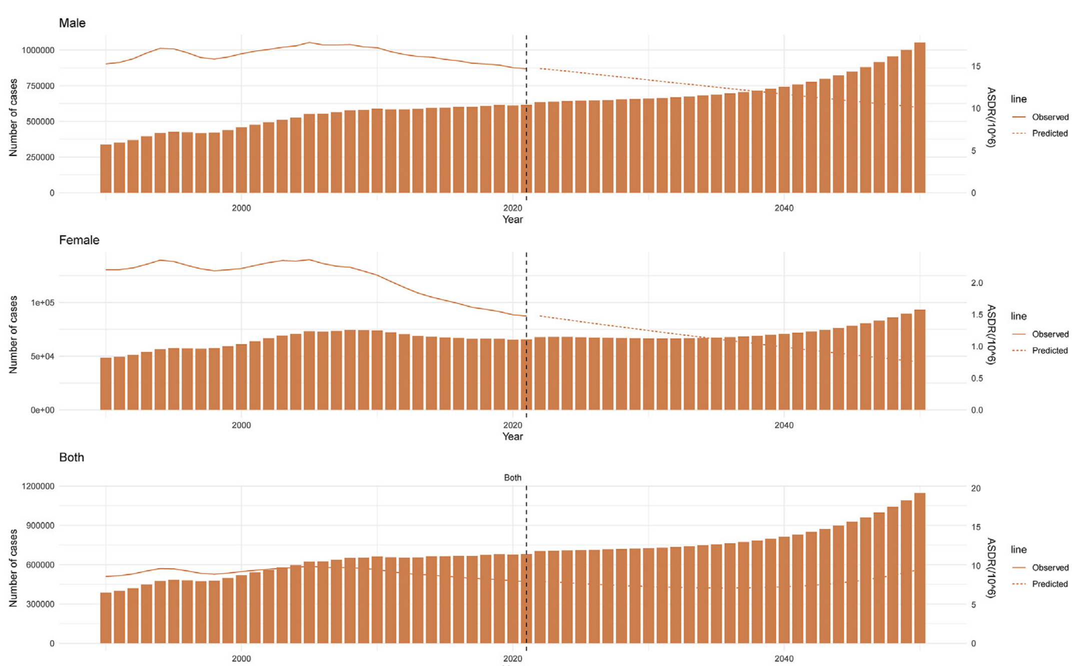

Fig. 7. BAPC predicts the global AAP burden and ASDR trend of different genders.

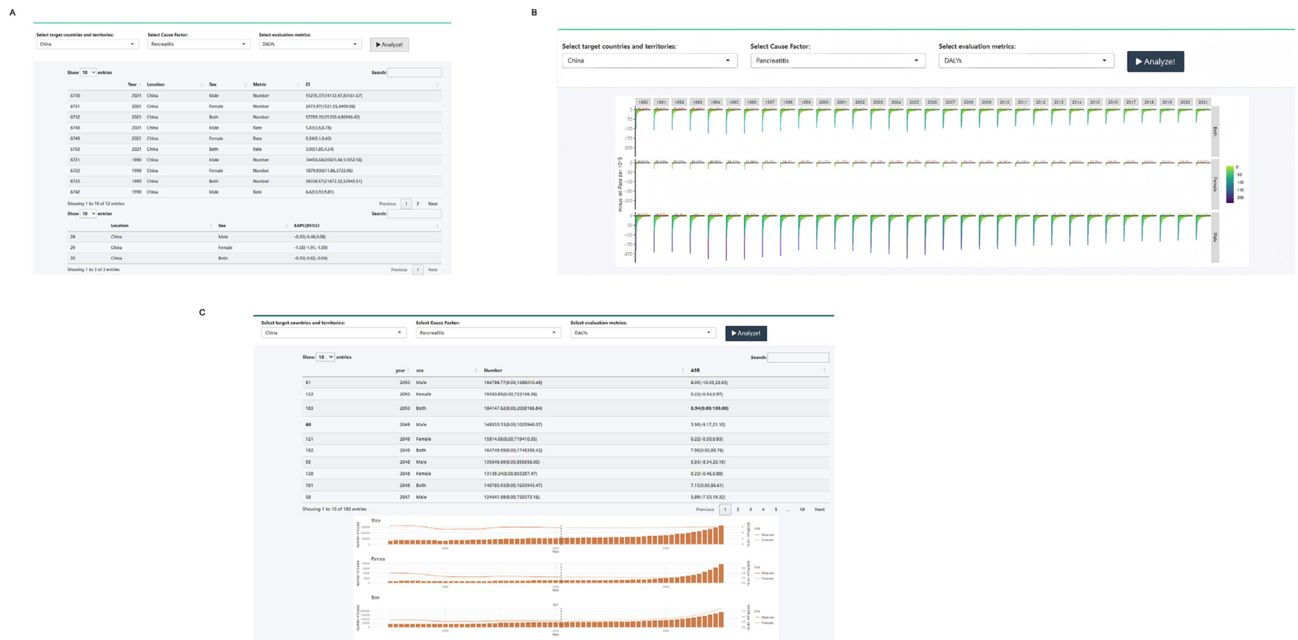

Fig. 8. Burden of AAP in China based on the GBD-AAP platform and its prediction A. Burden table of DALYs B. Ranking of China's burden in the world from 1990 to 2021 C. Prediction of the number of AAP burdens of different genders and the trend of ASDR in China based on BAPC.

burden of AAP, including DALYs and mortality, with detailed analyses by region, sex, and age. Using the APC model, we assessed the effects of age, cohort, and period on ASDR across SDI regions, while decomposition analysis further quantified the contributions of population growth, aging, and epidemiological changes. To facilitate accurate burden evaluation in 204 countries and regions, we also developed the GBD-AAP platform for visualization. We found that while the global burden of AAP is projected to decline overall by 2050, it is expected to increase in low and middle SDI regions. Although males contribute the most to the AAP burden, the burden among younger populations (both male and female) continues to rise in some regions, particularly in low and middle SDI areas, indicating that alcohol consumption and related health issues among young people have not been effectively controlled. Moreover, the relationship between SDI and ASDR exhibits significant regional differences. In low and low-middle SDI regions, the AAP burden is increasing significantly, especially among individuals under 40 years old, whereas in high SDI regions, the burden has been effectively managed. Overall, the AAP burden varies across regions, particularly in terms of gender and geography, highlighting the importance of implementing targeted policy interventions.

Increased alcohol consumption has been shown to significantly affect alcohol-related diseases, with per capita alcohol intake positively correlated with pancreatitis mortality. In Iceland, between 1980 and 2015, alcohol consumption rose by 73%, and the age-standardized incidence rate increased from approximately 5 cases annually in the initial four years to 9.5 cases annually in the later years of the study (Kristjan Hauksson et al., 2020). During this period, the average annual growth rate of acute alcohol-induced pancreatitis was 7%. Similar findings were observed in Finland, where an increased incidence of acute pancreatitis was associated with higher alcohol consumption (Jaakkola et al., 1993; Sand et al., 2006, p. P108). Interestingly, from 1985 to 1999, Lindkvist et al. reported a 5.1% reduction in alcohol-related pancreatitis in Malmö, Sweden. This decline coincided with a 36% reduction in alcohol sales in the region, as well as decreases in other markers of alcohol-related harm, such as the incidence of delirium tremens and liver cirrhosis mortality (Lindkvist, Appelros, & Jonas, 2004). In the Netherlands, approximately 1300 patients are hospitalized annually with their first episode of acute alcohol-related pancreatitis (Noor et al., 2021). The severity of acute alcohol-related pancreatitis varies, with 80% of cases classified as mild and 20% as severe or life-threatening. Severe complications include (infected) pancreatic necrosis and multi-organ failure (Marc et al., 2006). Alcohol is also the leading cause of chronic pancreatitis, a condition that is irreversible. Consequently, AAP poses a substantial global disease burden. Current management strategies emphasize reducing alcohol consumption to slow disease progression and managing associated complications (Gibbs et al., 2021).

Initially, we observed that, on a global scale, the absolute number of DALYs and deaths due to AAP has increased when compared to 1990, raising significant concerns. However, further analysis using EAPC revealed an opposite trend, with the EAPC for DALYs recorded at −0.317 (−0.537, −0.096) and for deaths at −0.269 (−0.46, −0.077). This indicates that the absolute burden of AAP has risen alongside global population growth, but after adjustment, ASDR and ASMR have both decreased relative to 1990 levels, a trend confirmed by EAPC. In other words, the global burden of AAP has generally declined. Nevertheless, further disaggregation revealed substantial regional disparities, particularly in Middle SDI, Low-middle SDI, and Low SDI regions. EAPC findings demonstrated that ASDR (Middle SDI: 0.488 [0.357, 0.619], Low-middle SDI: 1.55 [1.324, 1.776], Low SDI: 1.18 [0.972, 1.388]) and ASMR (Middle SDI: 0.613 [0.48, 0.745], Low-middle SDI: 1.605 [1.369, 1.842], Low SDI: 1.209 [0.997, 1.421]) continue to rise in these regions. For example, regions such as High-income North America and Tropical Latin America also exhibit this trend. These findings underscore the geographical disparities in the AAP burden.

Additionally, ASDR demonstrates significant gender-related differences, with males contributing a substantially higher proportion of the burden of alcohol-attributable pancreatitis (AAP). This disparity can be attributed to two primary factors. First, from a sociocultural perspective, males are the primary consumers of alcohol, as drinking often holds social significance in male-dominated interactions. Second, due to sex-specific physiological differences, males are at a significantly higher risk of developing

AAP compared to females. Hauksson (Kristjan Hauksson et al., 2020) reported that the observed rise in AAP incidence was predominantly driven by an increase in male cases, with little change in female cases, aligning with the findings of this study. Other research similarly indicates that the incidence of AAP among females is significantly lower than that among males (Birgisson et al., 2002; Hanna Vidarsdottir, Pall, Halla Vidarsdottir, Hildur Thorarinsdottir, & Einar, 2013). For instance, a prospective questionnaire-based study in Denmark found that alcohol consumption significantly increased the risk of pancreatitis in males but not in females (Louise, Morten, Ulrik, & Janne Schurmann, 2008). Further, recent studies did not identify any significant differences in alcohol consumption levels or types of alcoholic beverages between female patients with alcohol-related pancreatitis and those with alcohol use disorder but no pancreatitis history (Sigurdur Jon Juliusson et al., 2018), suggesting that the causal relationship between alcohol intake and acute pancreatitis in females remains unclear (Sigurdur Jon Juliusson et al., 2018). Moreover, research by Li et al. (2023) revealed that, after adjusting for confounding factors such as alcohol consumption and smoking, the risk of pancreatitis recurrence was significantly higher in males than females (HR = 1.63). These findings highlight that males not only exhibit higher susceptibility to AAP but also contribute more significantly to the overall burden, necessitating targeted attention and control measures.

We found significant differences in the ASDR burden of AAP across regions, especially in lower SDI areas, including Middle SDI, Low-middle SDI, and Low SDI regions. In these areas, the DALYs burden continued to rise across nearly all age groups, whereas high SDI regions achieved better control over disease burden during the same period. To further explore the correlation between ASDR and SDI, we observed a non-linear relationship between the two. In low and middle SDI regions, ASDR and SDI were positively correlated, but in high SDI regions, an inverse correlation was found. First, the persistent increase in AAP burden in low SDI regions can likely be attributed to insufficient medical resources and inadequate health education. In these regions, public awareness of alcohol-related diseases is low, and the limited reach of preventive health education has resulted in widespread excessive drinking behaviors (Jürgen Rehm et al., 2017). Additionally, a lack of healthcare infrastructure restricts early diagnosis and treatment, exacerbating disease progression and mortality rates. Second, variations in drinking patterns offer another important explanation. Research indicates that in low SDI regions, heavy episodic drinking (HED) is predominant and strongly associated with an increased risk of acute pancreatitis (Samokhvalov et al., 2015). In contrast, drinking behavior in high SDI regions tends to involve more moderate alcohol consumption, and a higher level of public awareness regarding health risks has likely contributed to a reduced incidence of AAP. Lastly, the effectiveness of policy interventions and public health measures varies substantially across SDI regions. High SDI regions often have comprehensive alcohol control policies, such as increased alcohol taxation and restrictions on alcohol sales times and locations, which have proven effective in reducing alcohol consumption and its associated disease burden (Anderson, Chisholm, & Daniela C., 2009). However, in low SDI regions, resource limitations and weak enforcement reduce the efficacy of such interventions.

To further investigate the impact of factors such as age, cohort effects, and period effects across regions with varying SDI levels, we constructed an APC model. The analysis revealed that cohorts born closer to the contemporary period exhibited more effective control over ASDR. In High SDI and High-middle SDI regions, ASDR trends showed significant improvement in the past five years, while Middle SDI, Low-middle SDI, and Low SDI regions demonstrated a concerning upward trend. This underscores the urgent need for policy reforms in lower SDI regions to mitigate the growing health burden in these areas. Combining this analysis with decomposition results, we identified population growth as the primary driver of AAP burden, with increases predominantly affecting younger and middle-aged populations. This trend is evident in all regions except High SDI areas, where ASDR among individuals under 40 years remains on the rise. In middle- and low-SDI regions, particularly in developing countries, rapid economic growth and social transitions have often driven spikes in alcohol consumption, accompanied by inadequate regulation. One contributing factor is the affordability and accessibility of alcohol in these regions, including both commercially produced and home-brewed options. Homebrewed and illicit alcohol may contain higher concentrations of toxic substances (e.g., methanol), exacerbating pancreatic damage. Additionally, high levels of social pressure in low-income countries encourage young individuals to rely on alcohol as a coping mechanism, combined with insufficient awareness regarding the long-term health risks of excessive drinking. Furthermore, many middle- and low-SDI regions lack effective alcohol control policies, such as minimum drinking age enforcement, sufficient alcohol taxation, or alcohol abuse prevention programs, leading to the prevalence of high-risk drinking behaviors among younger populations.

Projections estimate that by 2050, the global burden of AAP will reach 1.146 million cases, with males continuing to account for the majority (approximately 1.053 million). Furthermore, differences in economic conditions, policies, and healthcare systems across countries and regions pose challenges to accurately evaluating AAP burdens. To address this issue, this study developed a personalized, free visualization platform to comprehensively assess the disease burden and forecast trends for each country and region, thereby facilitating the targeted implementation of health policies. Using China as an example, AAP burden in 2021 showed a declining trend, but its global ranking rose significantly from 1990. Notably, the ranking of females slightly declined, indicating that AAP burden in China still requires further control and intervention.

In summary, the burden of AAP is fundamentally a population-driven health challenge. This study applied the APC model, combined with decomposition analysis, to quantify the contributions of different factors, providing a more detailed insight into the AAP burden in high, middle, and low SDI countries over the past three decades. It identified high-risk trends among young males and in low and middle SDI regions and developed a free, comprehensive visualization platform to support data-driven policy interventions and propose systematic public health strategies. From 1990 to 2021, the global AAP burden showed an overall declining trend; however, in low and middle SDI regions, the burden continued to rise, particularly among younger populations. Males remained the primary contributors to the global AAP burden, but there was also a significant aging trend, especially in middle, low-middle, and low SDI regions. Additionally, a positive correlation was observed between SDI and ASDR in low SDI regions, while a negative correlation was found in high SDI regions, further emphasizing the importance of region-specific policy interventions based on socioeconomic levels. Building on these findings, this study proposes several policy recommendations. First, in low and middle SDI regions, stricter alcohol consumption regulations and enhanced public health education, particularly targeted at younger populations, should be implemented. Second, in low SDI regions, greater investment in medical resources is necessary to improve healthcare accessibility and enforce effective alcohol control policies. Lastly, in high SDI regions, existing policies should be further optimized, with a focus on identifying high-risk populations to prevent a resurgence of the AAP burden. These measures provide a structured and effective policy framework for addressing the global

AAP burden and lay the foundation for future public health initiatives. Moving forward, we aim to further expand the developed platform by integrating more real-time data or aligning it with national health databases to enable more precise trend forecasting and dynamic monitoring. Additionally, we plan to conduct linkage analyses between alcoholic pancreatitis and other related health issues, such as obesity, diabetes, and cardiovascular diseases, to provide more forward-looking recommendations.

This study has certain limitations. This study provides a comprehensive analysis of the disease burden, development trends and associated risk factors of AAP. However, it should be noted that this study mainly focuses on the analysis of risk factors and has not yet conducted a systematic and comprehensive comparison of the incidence and prevalence rates associated with AAP. We believe that future in-depth analysis of this part of the data will further improve the comprehensiveness and depth of the study. Furthermore, variations in economic development and the strength of healthcare systems across countries make it challenging for the GBD database to adopt a standardized approach for accurately assessing disease burden. Stronger leadership and sustained political commitment are essential for the continuous monitoring and evaluation of prevention programs.

CRediT authorship contribution statement

Tang Yujin: Writing – review & editing, Conceptualization, Data curation, Project Administration, Software, Supervision. **Dai Dandan:** Writing – original draft, Writing – review & editing, Visualization. **Zhong Qian:** Conceptualization, Methodology, Writing – original draft, Software. **Pan Wenhao:** Writing – original draft, Resources, Formal analysis. **Di Xingwei:** Writing – original draft, Software.

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