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Global burden and cross-country inequalities of nutritional deficiencies in adults aged 65 years and older, 1990–2021: population-based study using the GBD 2021

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Abstract

Background/objectives Nutritional deficiencies remain significant public health issues in older populations globally. This study evaluates the burden, trends, and cross-country inequalities of four common nutritional deficiencies (protein-energy malnutrition, iodine deficiency, vitamin A deficiency, and dietary iron deficiency) in older adults from 1990 to 2021.

Methods Age-standardised prevalence, disability-adjusted life years (DALYs), and average annual percentage changes (AAPCs) of these deficiencies in people aged ≥ 65 years at global, regional, and national levels were estimated from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2021. Cross-country inequalities in disease burden were quantified using the slope index and concentration index, standard health equity methods recommended by the World Health Organization.

Results Globally, age-standardised prevalence rates of protein-energy malnutrition increased from 1407.16 per 100 000 population in 1990 to 2015.58 in 2021, with an AAPC of 1.18 (1.08–1.28), showing significant changes in 2015 and 2019, which were turning points in the joinpoint regression. Age-standardised prevalence rates of iodine, vitamin A, and dietary iron deficiencies decreased, with AAPCs of -0.49 (-0.53 to -0.44), -3.24 (-3.27 to -3.20), and – 0.14 (-0.17 to -0.12), respectively. Except for an increase in the DALY rate of vitamin A deficiency (AAPC 0.40), the DALY rates of the other three deficiencies decreased. Inequality in the burden of protein-energy malnutrition and iodine deficiency between high- and low-income countries narrowed, while inequality for vitamin A and dietary iron deficiencies remained stable. Age-standardised DALY rates for all deficiencies decreased as sociodemographic index increased.

Conclusions The global status of nutritional deficiency among older adults has improved since 1990, but the increasing prevalence of protein-energy malnutrition requires attention. Additionally, cross-country health inequalities persist, necessitating more efficient public health measures.

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Keywords Nutritional deficiencies, Health inequities, Ageing, Global burden of disease, Prevalence, Disability-adjusted life year

Introduction

Nutritional deficiencies remain substantial medical and public health issues worldwide. Common nutritional deficiencies encompass protein-energy malnutrition (PEM) and a range of micronutrient deficiencies such as iodine, vitamin A, iron, zinc, folate [1, 2]. Based on the data from Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2021, we focused on PEM and deficiencies of iodine, vitamin A, and iron. PEM is prevalent in both high-income and low- and middle-income countries [3]. A lack of iodine intake results in inadequate thyroid hormone production. Iodine deficiency affects two billion people, especially those in Africa and South Asia [4]. Vitamin A deficiency is a risk factor for infection [5], vision loss [6], and cognitive impairment [7]. In 2019, the global incidence of vitamin A deficiency was estimated at 489 million cases [8]. Iron deficiency, and iron deficiency anaemia, cause an immense disease burden worldwide. Globally, there were over 1.2 billion cases of iron deficiency anaemia [9].

The global ageing population is experiencing a remarkable surge, with approximately two billion people aged 65 and above by 2050 [10, 11]. This ageing population brings considerable societal challenges, as age-related diseases and declining health status can lead to disability and dependence [12]. Malnutrition is such a challenge. Due to physiological decline, reduced access to nutritious food, comorbidity, as well as social and economic factors, older persons are prone to malnutrition [13]. According to the UK National Diet and Nutrition Survey (NDNS) 2014–2016 data, free-living individuals aged 75 years and over do not meet estimated average nutritional requirements [14]. Another study estimated that around a quarter of adults aged 65 years and older are malnourished or at risk of malnutrition, and this number is expected to rise with the rapid increase in the ageing population [15].

Universal health coverage is now an important concern in medical and public health. Currently, there still exists an unbalanced burden of nutritional deficiency among the elderly population. Higher prevalence rates of nutritional deficiencies have been reported in low-income regions [16] Under these circumstances, assessing the nutritional deficiency burden and health inequalities among older adults is crucial, which could, in turn, guide effective decision-making and resource allocation. To the best of our knowledge, there are only a limited number of analyses on nutritional deficiencies in elderly populations and in limited regions. Thus, in this study, we utilised data from the GBD 2021 to determine the temporal trends in the prevalence and disability-adjusted life years (DALYs) of four common nutritional deficiencies at global, regional, and national levels among people aged ≥ 65 years, and to analyse cross-country inequalities, aiming to provide new insight into the elderly's nutrition and promote public health.

Materials and methods

Data source

Data were obtained from the latest release of the Global Burden of Disease, Injuries, and Risk Factors Study (GBD) 2021. GBD 2021 combined the latest available epidemiological data to comprehensively estimate the global burden of 371 diseases, injuries, and impairments, and 88 risk factors for 204 countries and territories. Data collected by the GBD collaborator network were sourced from a variety of origins, including disease registry data, clinical informatics data, epidemiological surveillance data, household survey data, and other sources. Then the data underwent rigorous cleaning, transformation, and modelling processes to generate estimates (https://www.healthdata.org/data-tools-practices/data-collection). Prevalence and incidence were modelled using either a Bayesian disease modelling meta-regression tool named Disease Modelling Meta-Regression; version 2.1 (DisMod-MR 2.1) or spatiotemporal Gaussian process regression (ST-GPR) [17]. The years of life lost (YLL) were calculated as the product of estimated age-sex-location-year-specific deaths and the standard life expectancy at the age death occurred for a given cause [18]. Years lived with disability (YLD) were calculated by multiplying the number of patients by the duration until remission or death, along with the disability weight. DALYs, representing a population's average number of years of life spent in good health, is the sum of the YLL and YLD [19]. The detailed methodologies employed in the GBD 2021 have been described elsewhere [17]. In this study, numbers, rates, and their 95% confidence intervals (CIs) of prevalence and DALYs of four common nutritional deficiencies (protein-energy malnutrition, iodine deficiency, vitamin A deficiency, and dietary iron deficiency) were reported in people aged ≥ 65 years for both sexes from 1990 to 2021. Patient age was classified into seven subgroups: 65–69 years, 70–74 years, 75–79 years, 80–84 years, 85–89 years, 90–94 years, and ≥ 95 years.

We also calculated the sociodemographic index (SDI) for each country, which is a composite indicator of social and economic conditions influencing health outcomes in each location. The SDI takes into account fertility rates among females younger than 25 years, mean education for those over 15 years old, and income per capita, ranging from 0 to 1, where 0 represents the minimum level of development and 1 represents the maximum level. Countries/territories are divided into five categories based on SDI values: high SDI (> 0.810), high-middle SDI (0.712–0.810), middle SDI (0.619–0.712), low-middle SDI (0.466–0.619) and low (< 0.466) [20]. The SDI values for all countries/territories in GBD 2021 are presented in Supplementary File 1.

Disease definitions

Protein-energy malnutrition (PEM) includes moderate and severe acute malnutrition, commonly referred to as "wasting", and was defined in terms of weight-for-height Z-scores (WHZ) on the World Health Organization (WHO) 2006 growth standard for children. PEM was quantified in four categories: moderate wasting without oedema (WHZ < -2SD to < -3 SD), moderate wasting with oedema (WHZ < -2SD to < -3 SD), severe wasting without oedema (WHZ < -3SD), and severe wasting with oedema (WHZ < -3SD). The GBD team further uses the DisMod-MR 2.1 model to ensure consistent applicability of the assessment across all age groups. For PEM, ICD 10 codes are E40-E46.9, E64.0, and ICD 9 codes are 260-263.9 [17]. In the GBD 2021, the non-fatal burden of iodine deficiency includes estimates of only the subset of iodine deficiency associated with visible goitre (grade 2) and its associated sequelae, including thyroid dysfunction, heart failure, and intellectual disability, excluding sub-clinical iodine deficiency or non-visible goitre (grade 1) induced by iodine deficiency. For iodine deficiency, ICD-10 codes are E00-E02 and ICD-9 codes are 244.2 [17]. Vitamin A deficiency was defined as the prevalence of serum retinol concentration < 0.7 μmol/L, according to ICD 10 codes E50-E50.9, E64.1, and ICD 9 codes 264-264.9 [17]. Dietary iron deficiency is defined as mild, moderate, or severe anaemia that is the result of inadequate dietary intake of iron, but not due to other causes of inadequate absolute or functional iron availability to meet the body's needs. For dietary iron deficiency, ICD 10 codes are D50-D50.9, and ICD 9 codes are 280-280.9 [17].

Statistical analysis

Descriptive analysis

To characterise the burden of four common nutritional deficiencies among adults aged ≥ 65 years, a descriptive analysis was performed at global, regional (21 GBD geographical regions), and national (204 countries and territories) levels. The age-standardised rates (ASRs), including the age-standardised prevalence rate (per 100 000 population) and age-standardised DALY rate (per 100 000 population), and corresponding 95% CIs were calculated based on the world standard population reported in the GBD 2021. The ASRs per 100,000 people were calculated according to the following formula: ASR $= \frac{\sum_{i=1}^{A} a_i w_i}{\sum_{i=1}^{A} w_i}$, where a_i is the age specific rate and w_i is the weight in the same age subgroup of the chosen reference standard population (in which i denotes the i^{th} age class) and A is the upper age limit.

Trend analysis

Average annual percentage changes (AAPCs) were calculated by joinpoint regression analysis to measure the temporal trend of ASR from 1990 to 2021. AAPCs are weighted averages of the annual percentage changes (APCs), allowing us to use a single number to describe the average APCs over a multi-year period. If the AAPC estimation and 95% CIs were both > 0, the ASR was considered to be in an upward trend during a certain period. Conversely, if the AAPC estimation and 95% CIs were both < 0, the ASR was considered to be in a decreasing trend. Otherwise, the trend was deemed to be stable [21]. The AAPC value indicates the APC. For example, a value of AAPC 0.1 implies a 0.1% annual increase rate. AAPC was calculated using the following equation: AAPC = $\left\{ exp\left(\frac{\sum w_i b_i}{\sum w_i} \right) - 1 \right\} \times 100$, where b_i is the slope coefficient for the i^{th} segment with i indexing the segments in the desired range of years, and w_i is the length of each segment in the range of years.

Inequality analysis

Two standard metrics recommended by WHO, the slope index and concentration index, were applied to measure absolute and relative cross-country inequality, respectively [22, 23]. The slope index was calculated by regressing the national age-standardised DALY rates in the all-age population on an SDI-associated relative position scale, defined as the midpoint of the cumulative range of the population ranked by SDI. The concentration index was calculated by numerically integrating the area under the Lorenz concentration curve, which was fitted using the cumulative fraction of prevalence and cumulative relative distribution of the population ranked by SDI [24]. If the Lorenz curve lies above the line of equality, the health burden is concentrated among low-income countries, represented by a negative concentration index [23]. We also used scatter diagrams and smoothing spline models to test for associations between ASRs in 2021 and SDI. The statistical analyses were conducted using R Studio (version 4.4.0) and the Joinpoint Regression Program (version 5.0.2).

Results

PEM

Overall, the global age-standardised prevalence rate (ASPR) of PEM among older people aged ≥ 65 years increased between 1990 and 2021, from 1407.16 per 100 000 population in 1990 to 2015.58 per 100 000 population in 2021, with an AAPC of 1.18 (1.08–1.28). Joinpoint regression analysis showed that the prevalence of PEM increased between 1990 and 2015, then decreased between 2015 and 2019, and continued to increase significantly between 2019 and 2021. Years with greater changes in the prevalence were 2015 and 2019 (Table 1; Fig. 1A). The overall age-standardised DALY rates from PEM decreased in the population aged ≥ 65 years, from 340.38 per 100,000 population in 1990 to 177.79 per 100 000 population in 2021, with an AAPC of -1.93 (-4.17 to 0.36) (Supplementary Table 1, Figure S1A).

Among seven age subgroups, the highest proportion of prevalence cases was observed among those aged 65–69 years (AAPC 1.10). The highest proportion of DALYs cases was observed among those aged 70–74 years (AAPC − 2.44). In 2021, the age standardised prevalence and DALYs rate of PEM increased with age (Supplementary Tables 2 and 3, Figure S2).

Regionally, the highest ASPR of PEM among people aged ≥ 65 years was observed in East Asia (2502.41 per 100 000), whereas the highest rate of DALYs was in Eastern sub-Saharan Africa (1070.43 per 100 000 population) in 2021 (Supplementary Tables 4 and 5, Figure S3).

Nationally, France had the highest ASPR of PEM among older people (4504.38 per 100 000), followed by Antigua and Barbuda (4358.61 per 100 000) and Indonesia (3881.93 per 100 000) in 2021 (Supplementary Table 6, Fig. 2A). The highest rate of DALYs was found in Somalia (2784.04 per 100 000), followed by Sierra Leone (2204.00 per 100 000) and Kiribati (2181.48 per 100 000) (Supplementary Table 6, Fig. 2B).

A higher prevalence was observed to disproportionately concentrate in countries with low SDI in 1990, but with remarkable improvement in these inequalities over time. As shown in Fig. 3A, the gap in ASPR between the highest and lowest SDI countries decreased significantly, with the slope index changing from − 630 (95% CI: -991 to -268) in 1990 to 583 (95% CI: 291–874) in 2021. Moreover, the concentration index presented − 0.06 (95% CI: -0.10 to -0.02) in 1990 and 0.02 (95% CI: -0.01 to 0.05) in 2021, indicating a nearly balanced distribution of the burden among countries with different SDI (Fig. 3B). The associations between the age-standardised DALY rate and SDI among all countries/territories in 2021 are shown in Fig. 4A. As the SDI values increased, the age-standardised DALY rate decreased.

Iodine deficiency

Globally, joinpoint regression analysis identified that although there was an increase in the prevalence of iodine deficiency in 2000 and 2005, the overall prevalence of iodine deficiency decreased during 1990–2021, from 1921.43 per 100 000 population in 1990 to 1656.34 per 100 000 population in 2021 (AAPC − 0.49) (Table 1; Fig. 1B). The pattern and trends of the age-standardised DALY rates were similar to those of the ASPR, from 27.60 per 100,000 population in 1990 to 18.61 per 100 000 population in 2021, with an AAPC of -1.29 (Supplementary Table 1, Figure S1B).

The highest proportion of prevalence and DALYs cases occurred among those aged 65–69 years (AAPC − 0.56 and AAPC − 1.37). In 2021, the age standardised prevalence and DALYs rate of iodine deficiency decreased with age (Supplementary Tables 2 and 3, Figure S4). Among the 21 regions, Central Sub-Saharan Africa showed the highest ASR of prevalence and DALYs of iodine deficiency among older people aged ≥ 65 years in 2021 (Supplementary Tables 4 and 5, Figure S5).

At the national level, the highest ASPR of iodine deficiency among older people aged ≥ 65 years in 2021 was observed in Somalia (24331.41 per 100 000 population), followed by Djibouti (14559.16 per 100 000) and the Democratic Republic of the Congo (13858.91 per 100 000). The pattern and trends of the age-standardised DALY rates were similar to those of the ASPR (Supplementary Table 6, Fig. 2C and D).

The slope index was − 1863(95% CI: -2267 to -1459) in 1990 and − 870 (95% CI: -1132 to -608) in 2021, respectively. This decline indicates that the inequality in the burden of iodine deficiency among the elderly population between high-income and low-income countries narrowed during this period. Moreover, the concentration index presented − 0.48 (95% CI: -0.57 to -0.38) in 1990 and − 0.38 (95% CI: -0.45 to -0.30) in 2021, indicating a reduction in health inequality (Fig. 3C and D). Figure 4B showed that throughout all regions and countries, those with higher SDI experienced a lower ASR of DALYs of iodine deficiency in 2021.

Vitamin A deficiency

During the past 32 years, the global ASPR of vitamin A deficiency among the ageing population decreased in all periods, from 6538.09 per 100 000 population in 1990 to 2362.40 per 100 000 population in 2021 (AAPC − 3.24) (Table 1; Fig. 1C). The age-standardised DALY rates due to vitamin A deficiency showed a slight increasing trend, from 1.57 per 100 000 population to 1.75 per 100 000 population (AAPC 0.40) (Supplementary Table 1, Figure S1C).

The highest proportion of prevalence and DALYs cases were observed in the 65–69 years age group (AAPC

Table 1 Age-standardised prevalence and AAPC of four nutritional deficiencies in people aged ≥ 65 years, 1990–2021

	1990		2021		1990–2021
	Number (95%CI)	**ASR per 100 000 (95%CI)**	**Number (95%CI)**	**ASR per 100 000 (95%CI)**	**AAPC (95% CI)**
Protein-energy malnutrition					
Global	4533314.83 (3740940.41-5443113.27)	1407.16 (1159.79-1690.26)	15418031.39 (13149016.88-18111133.28)	2015.58 (1718.78-2367.40)	1.18 (1.08–1.28)
Sex					
Male	2089330.08 (1721512.82-2516383.83)	1519.93 (1249.91-1832.75)	7665386.59 (6536509.70-9025533.44)	2225.14 (1897.74-2619.26)	1.26 (1.1–1.41)
Female	2443984.75 (2019696.53-2931794.96)	1326.67 (1095.49-1591.91)	7752644.80 (6598829.00-9113227.80)	1843.74 (1569.29-2167.25)	1.07 (0.98–1.17)
SDI					
Low	272668.44 (230613.43-322522.81)	1707.15 (1441.17-2021.90)	503498.17 (439009.58-582295.65)	1386.26 (1208.21-1603.88)	-0.58 (-0.72 to -0.44)
Low-middle	750650.90 (626440.19-888899.69)	1723.28 (1435.95-2042.36)	1942701.44 (1660593.37-2268162.15)	1722.71 (1471.01-2012.71)	0.09 (-0.06 to 0.25)
Middle	1223587.14 (1003586.96-1474589.36)	1611.35 (1320.91-1941.28)	5033988.40 (4252316.14-5970592.70)	2215.08 (1870.79-2628.27)	1.07 (0.82–1.33)
High-middle	750427.91 (611639.40-917760.19)	906.11 (737.76-1108.34)	3601310.65 (3051227.16-4275717.85)	1970.68 (1669.24-2339.36)	2.54 (2.42–2.65)
High	1532557.63 (1248193.35-1865536.14)	1477.05 (1202.44-1798.31)	4326467.23 (3670283.24-5071469.19)	2094.95 (1777.94-2454.85)	1.09 (0.96–1.22)
Iodine deficiency					
Global	6470413.55 (5086545.89-7969931.60)	1921.43 (1507.89-2372.80)	12946214.16 (9922929.15-16177960.19)	1656.34 (1269.07-2071.38)	-0.49 (-0.53 to -0.44)
Sex					
Male	2460245.87 (1937755.60-3032741.71)	1674.08 (1314.46-2071.66)	4274077.99 (3286461.02-5337035.35)	1189.27 (913.92-1487.16)	-1.10 (-1.15 to -1.05)
Female	4010167.68 (3138970.81-4958974.30)	2117.87 (1656.38-2622.54)	8672136.17 (6625800.46-10830170.69)	2055.46 (1570.55-2567.22)	-0.10 (-0.13 to -0.07)
SDI					
Low	1177685.68 (943188.46-1411598.54)	6825.82 (5442.79-8233.69)	2069207.53 (1588309.44-2542534.70)	5385.25 (4126.63-6640.75)	-0.76 (-0.81 to -0.71)
Low-middle	2347895.14 (1829444.98-2873177.92)	5056.67 (3929.05-6215.12)	3800169.32 (2869125.76-4763413.71)	3226.17 (2431.83-4054.98)	-1.46 (-1.51 to -1.41)
Middle	1389265.77 (1068264.90-1749853.90)	1718.50 (1318.40-2172.94)	3797472.57 (2900564.73-4779945.89)	1611.29 (1229.43-2031.44)	-0.22 (-0.28 to -0.16)
High-middle	1054281.91 (803220.55-1332658.32)	1249.80 (950.85-1583.21)	2433829.12 (1847060.76-3066390.96)	1312.91 (995.91-1655.42)	0.15 (0.11–0.19)
High	498802.24 (377317.71-639797.48)	478.15 (361.79-613.67)	842025.77 (638086.15-1076099.43)	417.71 (316.86-533.09)	-0.43 (-0.45 to -0.42)
Vitamin A deficiency					
Global	21720851.05 (18803804.40-25319372.74)	6538.09 (5663.33-7617.42)	18339086.80 (15404661.35-22318642.67)	2362.40 (1984.25-2874.99)	-3.24 (-3.27 to -3.20)
Sex					
Male	12379582.41 (9831846.80-15543037.78)	8670.26 (6882.29-10894.10)	9267402.50 (6894317.44-13026085.81)	2614.56 (1945.34-3671.82)	-3.80 (-3.85 to -3.76)
Female	9341268.64 (7916625.48-11269249.28)	4974.83 (4218.89-5996.64)	9071684.30 (7451532.03-11345068.46)	2153.70 (1768.77-2694.39)	-2.66 (-2.72 to -2.60)
SDI					
Low	5701770.55 (5078408.16-6403349.51)	34715.80 (30897.84-39035.14)	5215881.00 (4428973.55-6256640.29)	13988.94 (11867.65-16779.86)	-2.88 (-2.96 to -2.81)
Low-middle	8446120.45 (6514927.03-10891916.75)	18864.01 (14583.49-24266.38)	6661192.92 (4894619.98-9226223.70)	5811.53 (4270.98-8043.42)	-3.74 (-3.79 to -3.69)

Table 1 (continued)

	1990		2021		1990–2021
	Number (95%CI)	**ASR per 100 000 (95%CI)**	**Number (95%CI)**	**ASR per 100 000 (95%CI)**	**AAPC (95% CI)**
Middle	3849558.02 (3134135.67-4718453.01)	4915.59 (4008.68-6017.27)	3598634.35 (2872529.86-4556533.83)	1561.58 (1246.90-1977.57)	-3.63 (-3.67 to -3.59)
High-middle	2739731.07 (2346262.51-3167032.69)	3288.77 (2815.66-3805.63)	2154044.73 (1823658.43-2540753.01)	1175.54 (994.93-1386.89)	-3.26 (-3.29 to -3.24)
High	949976.50 (729114.88-1240591.72)	910.66 (699.00-1189.29)	681447.73 (502911.33-925013.16)	334.81 (246.70-454.47)	-3.17 (-3.21 to -3.14)
Dietary iron deficiency					
Global	49843846.82 (47369690.94-52556025.95)	15520.14 (14712.46-16405.71)	113365952.44 (106924126.16-120391445.36)	14845.71 (13989.79-15780.29)	-0.14 (-0.17 to -0.12)
Sex					
Male	24352714.48 (22867769.02-25895100.80)	18271.23 (17119.36-19472.94)	50245529.25 (46206535.49-55007935.44)	15073.06 (13849.93-16522.61)	-0.62 (-0.64 to -0.60)
Female	25491132.34 (23740364.50-27243461.53)	13807.05 (12830.02-14794.86)	63120423.20 (58943944.26-67890974.50)	14981.74 (13991.27-16113.86)	0.27 (0.25–0.28)
SDI					
Low	4967353.99 (4614562.84-5343056.48)	31269.89 (29118.07-33536.62)	11796287.78 (10833582.21-12814008.24)	32539.75 (30007.91-35214.84)	0.13 (0.11–0.15)
Low-middle	14793276.58 (13918939.35-15782138.48)	33667.41 (31643.90-35921.99)	37096138.30 (34536566.29-39883580.39)	32716.25 (30449.39-35211.45)	-0.09 (-0.11 to -0.07)
Middle	15573875.24 (14519832.19-16665191.96)	20726.35 (19305.41-22192.02)	38016494.23 (34919791.16-41413015.80)	16971.54 (15588.11-18482.20)	-0.64 (-0.68 to -0.61)
High-middle	9019819.27 (8093898.03-10097921.97)	11380.38 (10169.43-12803.02)	15600372.74 (13878410.25-17598031.83)	8698.85 (7728.95-9821.80)	-0.86 (-0.93 to -0.79)
High	5448212.58 (4541790.91-6509874.51)	5377.61 (4480.68-6424.53)	10783782.13 (8641738.74-13607094.50)	4929.39 (3953.57-6229.07)	-0.27 (-0.33 to -0.20)

SDI, sociodemographic index

−3.32 and AAPC 0.40). In 2021, the age standardised prevalence and DALYs rate of vitamin A deficiency decreased with age (Supplementary Tables 2 and 3, Figure S6). Regionally, Eastern sub-Saharan Africa had the highest ASPR of vitamin A deficiency in 2021 (19797.35 per 100 000 population). Central Sub-Saharan Africa had the highest ASR of DALYs of vitamin A deficiency in 2021 (10.00 per 100 000 population) (Supplementary Tables 4 and 5, Figure S7).

Nationally, the highest ASPR of vitamin A deficiency in 2021 appeared in Somalia (78833.75 per 100 000 population), followed by Niger (38991.84 per 100 000 population) and South Sudan (34523.92 per 100 000 population). The Congo had the highest rate of DALYs (14.37 per 100 000 population), followed by Equatorial Guinea (13.74 per 100 000 population) and Angola (12.02 per 100 000 population) (Supplementary Table 6, Fig. 2E and F).

The ASPR disproportionately concentrated in countries with low SDI. As shown in Fig. 3E and F, the gap in ASPR between the highest and lowest SDI countries decreased, with the slope index changing from −31,631 (95% CI: -35571 to -27692) in 1990 to -9052 (95% CI: -10586 to -7519) in 2021. However, the concentration index, a measure of relative gradient inequality, remained nearly constant between 1990 (-0.55, 95% CI: -0.64 to -0.46) and 2021 (-0.55, 95% CI: -0.67 to -0.44). Figure 4C demonstrated that as the SDI values increased, there was a decline in the age-standardised DALY rate of vitamin A deficiency among people aged ≥ 65 years in 2021.

Dietary iron deficiency

The ASPR of dietary iron deficiency among the population aged ≥ 65 years slightly decreased worldwide, from 15520.14 per 100 000 population in 1990 to 14845.71 per 100 000 population in 2021, with an AAPC of -0.14. Males had a decreasing trend of dietary iron deficiency (AAPC −0.62). However, the ASPR of dietary iron deficiency among females slightly increased, with an AAPC of 0.27 (Table 1; Fig. 1D). The ASRs of DALYs of dietary iron deficiency decreased during this period, from 392.80 per 100 000 population in 1990 to 343.11 per 100 000 population in 2021 (AAPC −0.43) (Supplementary Table 1, Figure S1D).

Among the seven age subgroups, the highest proportion of prevalence and DALYs cases were observed in the 65–69 years age group (AAPC −0.34 and AAPC −0.80). In 2021, despite a modest decline observed in the 80–84 age group, the overall trend indicates that the

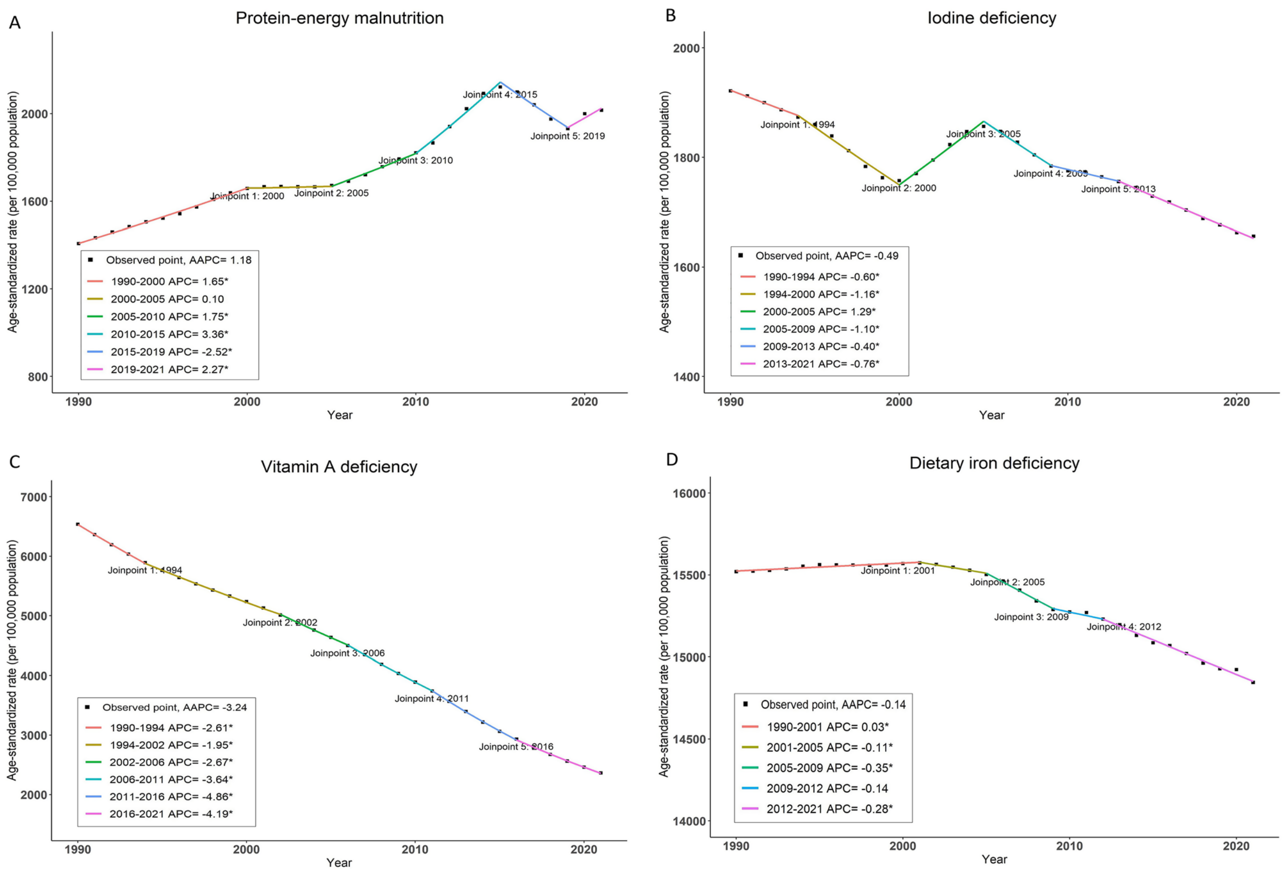

Fig. 1 Joinpoint regression analysis of global age-standardised prevalence of (**A**) Protein-energy malnutrition, (**B**) Iodine deficiency, (**C**) Vitamin A deficiency, (**D**) Dietary iron deficiency in people aged ≥ 65 years, 1990–2021. Abbreviations: APC, Annual percentage change; AAPC, average annual percent change

age-standardized prevalence and DALYs rate of dietary iron deficiency tend to increase with advancing age (Supplementary Tables 2 and 3, Figure S8).

In 2019, among the 21 regions, South Asia had the highest age-standardised rate of prealence and DALYs of dietary iron deficiency among people aged ≥ 65 years, with rates of 44349.25 per 100 000 population and 1355.09 per 100 000 population, respectively (Supplementary Tables 4 and Table 5, Figure S9).

At the national level, India had the highest age-standardised prevalence of iron deficiency among older people in 2021 (47067.98 per 100 000 population), followed by Pakistan (34371.22 per 100 000) and Fiji (31904.27 per 100 000). Similarly, India had the highest age-standardised rate of DALYs (1450.87 per 100 000 population), followed by Pakistan (1025.29 per 100 000) and Bhutan (996.00 per 100 000) in 2021 (Supplementary Table 6, Fig. 2G and H).

The ASPR was disproportionately concentrated among lower SDI countries. The gap in ASPR between the highest and lowest SDI countries remained stable, with slope indexes of -20,515 (95% CI: -22651 to -18378) in 1990 and – 18,162 (95% CI: -20126 to -16198) in 2021. Additionally, the concentration index remained steady, at -0.38 (95% CI: -0.42 to -0.34) in 1990 and – 0.39 (95% CI: -0.44 to -0.34) in 2021 (Fig. 3G and H). In 2021, countries/territories with higher SDI had a lower age-standardised DALY rate of dietary iron deficiency (Fig. 4D).

Discussion

This study provides the most up-to-date data on the prevalence, DALY rates, and their temporal trends of four common nutritional deficiencies among older adults aged 65 years and above in all countries/territories from 1990 to 2021. The ASPR of PEM increased, while the ASPR of iodine deficiency, vitamin A deficiency, and dietary iron deficiency decreased over the past 32 years. The age-standardised DALY rate of vitamin A deficiency increased, while the DALY rates of PEM, iodine deficiency, and dietary iron deficiency decreased. The inequality in the burden of PEM and iodine deficiency among the elderly population between high-income and low-income countries narrowed during this period. The age-standardised DALY rates of the four nutritional deficiencies decreased as the SDI increased.

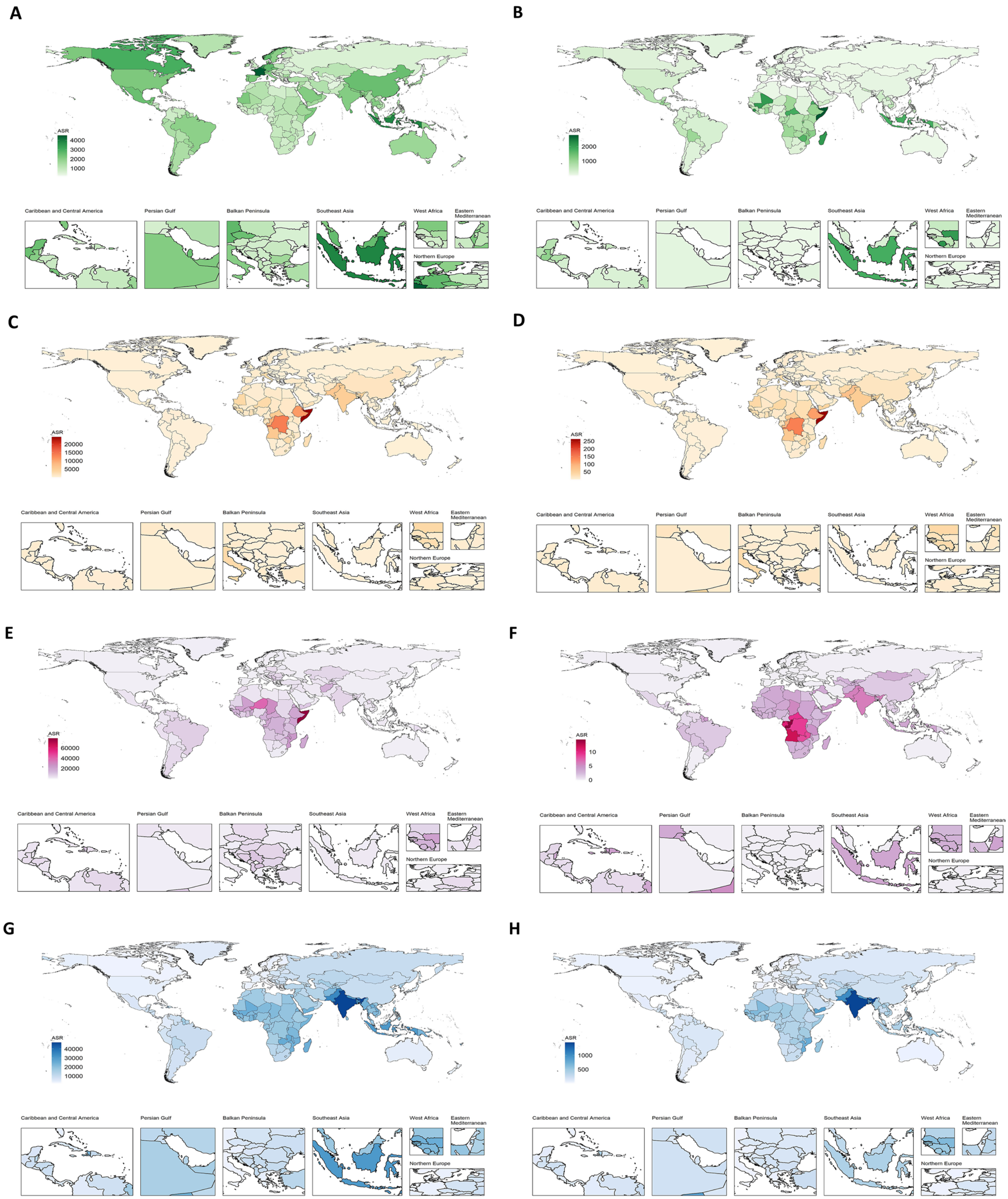

Fig. 2 The global disease burden of four nutritional deficiencies among people aged ≥ 65 years in 2021. (**A**) The age-standardised prevalence of protein-energy malnutrition; (**B**) The age-standardised DALY rates of protein-energy malnutrition; (**C**) The age-standardised prevalence of iodine deficiency; (**D**) The age-standardised DALY rates of iodine deficiency; (**E**) The age-standardised prevalence of vitamin A deficiency; (**F**) The age-standardised DALY rates of vitamin A deficiency; (**G**) The age-standardised prevalence of dietary iron deficiency; (**H**) The age-standardised DALY rates of dietary iron deficiency; Abbreviations: DALY, disability-adjusted life year

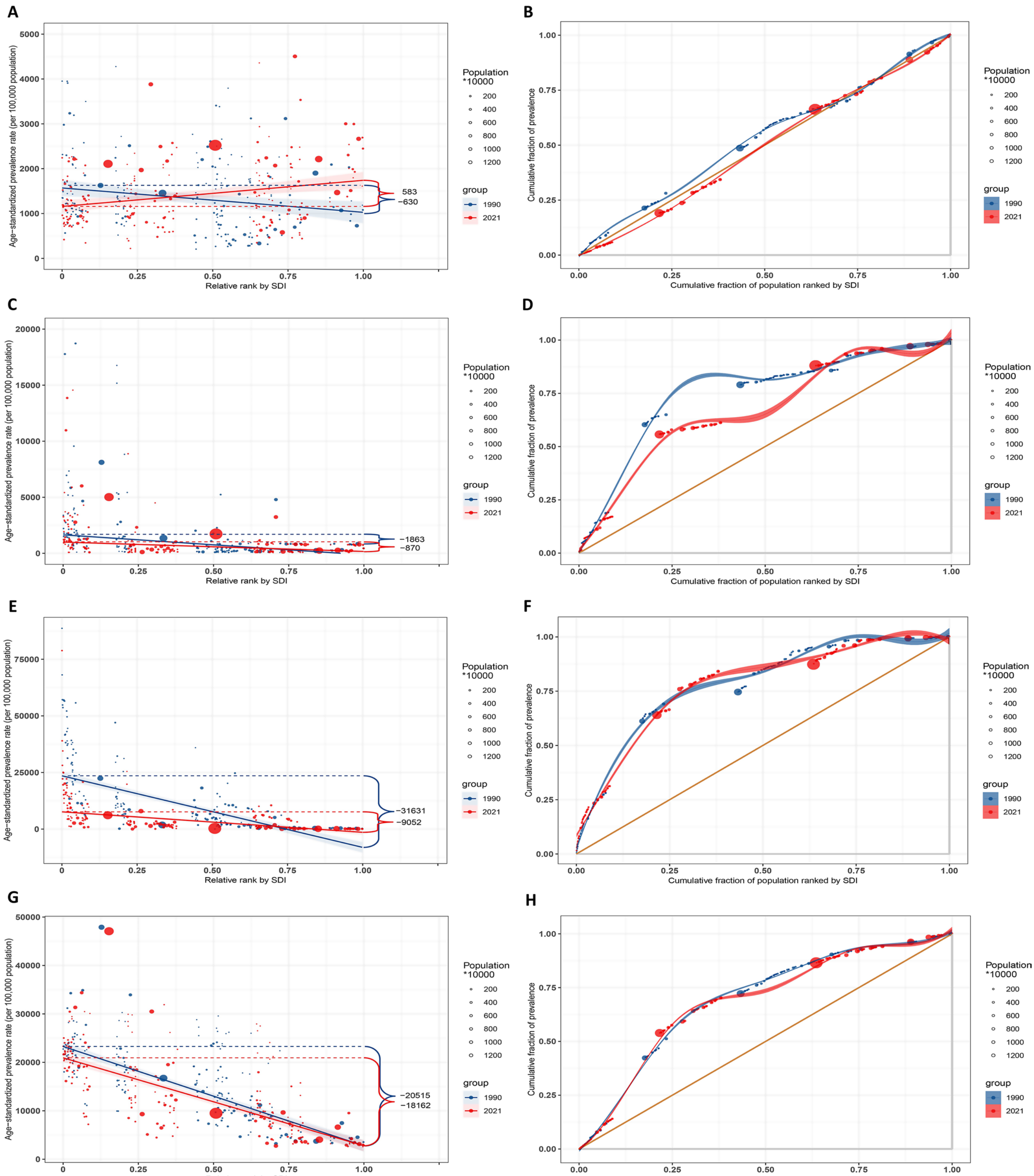

Fig. 3 Health inequality regression curves and concentration curves for the ASPR of protein-energy malnutrition (**A**-**B**), iodine deficiency (**C**–**D**), vitamin A deficiency (**E**-**F**), and dietary iron deficiency (**G**-**H**) among people aged ≥ 65 years worldwide, 1990 and 2021. Abbreviations: SDI, sociodemographic index

Globally, PEM in older adults varies due to different assessment tools and populations studied, with prevalence ranging from 3% to over 27% [13]. In this trend analysis study, we revealed that the global ASPR of PEM increased between 1990 and 2015, then declined between 2015 and 2019, and continued to increase remarkably between 2019 and 2021. Beginning in 2019, the world experienced the COVID-19 pandemic. PEM was highly prevalent among older adults infected with COVID-19. A Spanish cohort showed that malnutrition was found

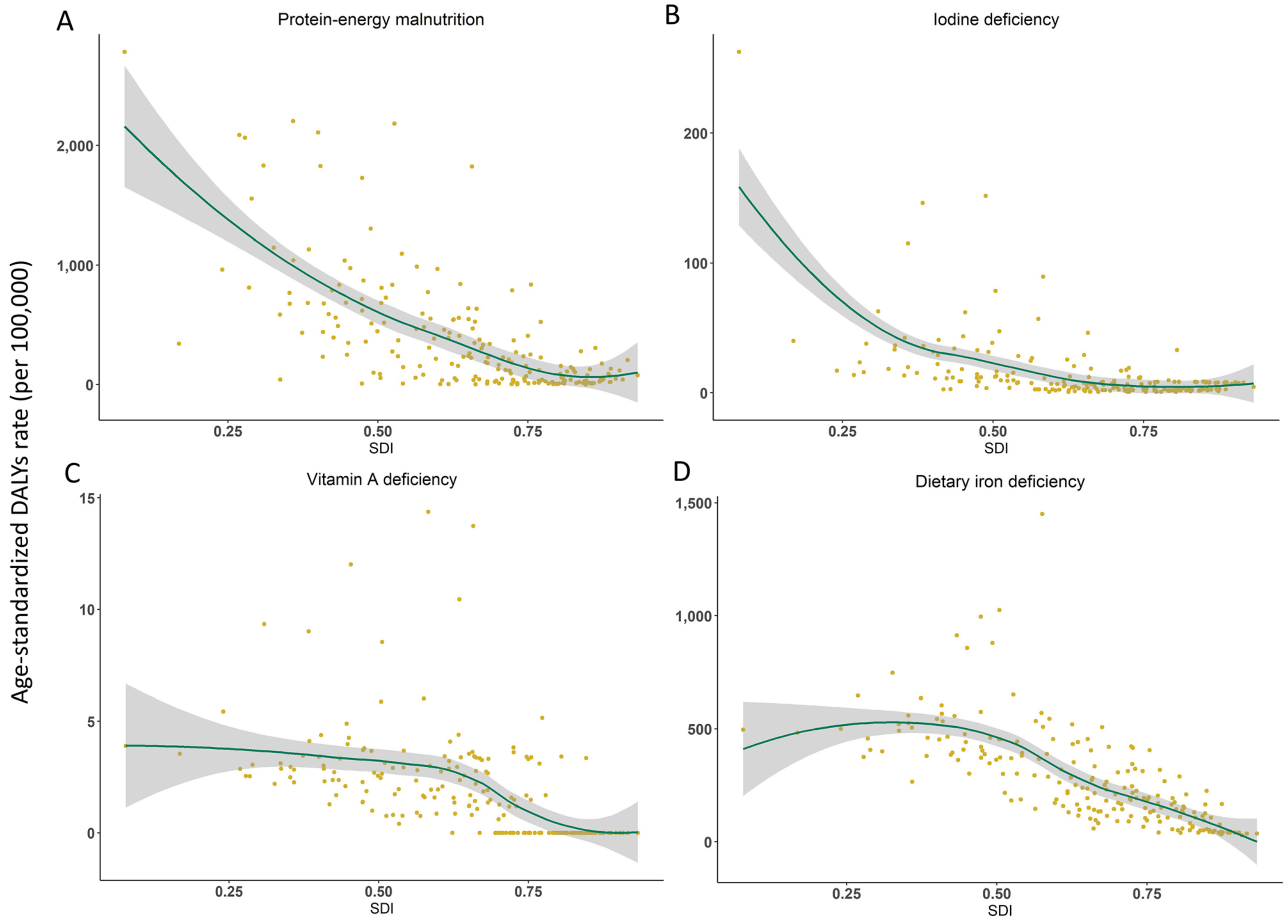

Fig. 4 The association between age-standardised DALY rate of (**A**) Protein-energy malnutrition, (**B**) Iodine deficiency, (**C**) Vitamin A deficiency, (**D**) Dietary iron deficiency and SDI across all countries/territories among people aged ≥ 65 years in 2021. Abbreviations: DALY, disability-adjusted life year; SDI, sociodemographic index

in 25% of COVID-19 survivors over 65 years of age [25]. In a Chinese cohort of hospitalised older adults infected with COVID-19, 52.7% were malnourished [26]. Compared with GBD 2019 and all previous GBD data, GBD 2021 provides the evidence base on the altered burden of disease landscape that ensued in 2020 and 2021, the first two years after the COVID-19 pandemic [17]. In our study, the prevalence of PEM began to rise from 2019, which may be partly related to the impact of COVID-19. The most common symptoms of COVID-19, such as fever, fatigue, and appetite loss are associated with reduced food intake, weight loss, and a higher risk of malnutrition [27]. COVID-19 has been reported to accelerate physical decline and frailty in institutionalized older adults by up to 20% [28]. Nearly 30% of COVID-19 patients lost more than 5% of their baseline body weight [27], a particular concern for older adults due to its relationship with muscle loss and frailty. Moreover, the pandemic worsened global food insecurity, with panic buying and hoarding causing price hikes and shortages [29, 30], which disproportionately affect older adults, especially those with comorbidities or lacking social support [31]. Disruptions in healthcare services [32] further hindered the management of PEM. Our findings highlight the need for comprehensive nutritional assessment and therapy as an integral part of geriatrics care in the post-COVID-19 period. However, the link between the post-2019 increase in PEM prevalence and COVID-19 remains speculative and requires future direct evidence. Regionally, the highest prevalence of PEM among people aged ≥ 65 years was observed in East Asia, and the highest rate of DALYs in Eastern sub-Saharan Africa in 2021. Maize is a staple food in countries in sub-Saharan Africa. Although it provides macro- and micronutrients the body needs, it lacks adequate amounts of essential amino acids [33]. Additionally, diets are mainly based on cereals and legumes instead of meat and animal offal, leading to inadequate protein intake in many parts of Africa [34]. The high prevalence in East Asia may be related to the general rapid ageing of countries in East Asia [35, 36]. Nationally, France had the highest ASPR of PEM among older people. A previous study spanning from 1990 to

2019 showed that the ASPRs of PEM in Western Europe were higher than predicted [3]. Being part of this region, France might align with this trend. The high prevalence of PEM in France may due to longer life span and improved nutritional screening [37], and relatively reliable data collection in high-income countries with comprehensive medical systems [38]. Further national surveys specifically focusing on PEM in France is needed.

Iodine is an essential trace element for thyroid hormone synthesis. It is reported that imbalances in iodine levels can contribute to neurocognitive disorders and narcolepsy in older adults [39, 40]. The WHO's first estimate of the global prevalence of goitre in 1960 suggested that 20–60% of the population worldwide was affected, with most of the burden in low- and middle-income countries [41]. Since 1990, the WHO has coordinated an international programme for the elimination of iodine deficiency [42], and salt iodisation has been widely adopted [43]. Over the past decades, there has been remarkable progress toward the prevention of iodine deficiency. UNICEF estimates that based on data collected during 2013–2018, 88% of the global population used iodised salt in 2018 [44]. National surveys revealed that until 2021, the number of iodine-deficient countries had fallen from 113 [45] to 21 [46]. However, inequality still exists, with a greater burden in disadvantaged regions. In 2013, the greatest proportion of individuals with iodine deficiency in general populations was in Africa (55%) [47]. In 2019, Western and Central Africa had the lowest coverage with iodised salt [44]. Our study showed that globally, the overall prevalence and DALYs of iodine deficiency decreased from 1990 to 2021. Central Sub-Saharan Africa regionally, and Somalia nationally, had the highest prevalence and DALYs of iodine deficiency, which was similar to the above literature among the general population.

Order adults are susceptible to deficiencies in fat soluble vitamins, including vitamin A [48]. Vitamin A deficiency is a potential risk factor for infection [5], vision loss [6], and cognitive impairment and mental illness [7]. To our best knowledge, there are limited analyses on the burden of vitamin A deficiency in elderly populations worldwide. Our study showed that the global ASPR and DALYs of vitamin A deficiency among the elderly decreased from 1990 to 2021. Eastern sub-Saharan Africa had the highest prevalence, and Central Sub-Saharan Africa had the highest DALY rate in 2021. As the SDI values increased, the age-standardised DALY rate declined, reflecting discrepancies in medical facilities and health care. Vitamin A deficiency is relatively more frequent in areas with lower socioeconomic levels [49, 50]. Results from GBD 2019 showed that sub-Saharan Africa, especially Central sub-Saharan Africa, had the highest age-standardised incidence and DALY rates of vitamin A deficiency, which is consistent with our results [8]. This imbalance may be due to poverty [51], lower education level [52], and availability of nutrients [53] in low-income regions. Additionally, in sub-Saharan Africa, widespread epidemics of infectious diseases like malaria and acquired immunodeficiency syndrome have resulted in the loss of vitamin A [54, 55]. In lower-income countries, the utilisation of vitamin A-rich foods through horticultural approaches might yield great benefits. There is also a need to foster research on fortified staples such as provitamin A enriched corn [56]. Moreover, in areas with perennially high temperatures like sub-Saharan Africa, proper preservation of drugs and food supplements ensuring vitamin A activity is also an important problem to be solved [57, 58].

Insufficient dietary iron intake is a contributor to anaemia in older individuals [59]. Reduced iron stores, regardless of anaemia status, are often associated with inflammation and an increased risk of physical and cognitive impairment among older adults [60]. Secondary analysis of the DO-HEALTH trial has reported that the prevalence of iron deficiency among older adults aged 70 and above varied from 8.5 to 49.8% across Europe [60]. Austria, Switzerland, and Germany also exhibited iron deficiency prevalence rates of 4.6%, 3.9%, and 3.2%, respectively [60]. Iron deficiency has been more common in disadvantaged subpopulations, including people in low-income countries/territories [61]. Our study showed that the ASPR and DALYs of dietary iron deficiency among the elderly decreased worldwide. Among the 21 regions, the highest ASPR and DALYs of dietary iron deficiency was in South Asia in 2021. At the national level, India had the highest ASPR and DALY rates of iron deficiency among older people. The ASPR disproportionately concentrated among lower SDI countries. The gap in ASPR between the highest and lowest SDI countries remained stable. The National Family Health Survey-4 (NFHS-4) revealed that India has the highest burden of anaemia worldwide [62]. These data highlight the necessity for monitoring and addressing iron deficiency at the older population level, considering geographical disparities [60]. The use of fortification of food with iron and multiple-micronutrients might address the problem of iron deficiency [63].

Among the seven age subgroups, the ASPR and DALYs of PEM and dietary iron deficiency increased, while ASPR and DALYs of iodine and vitamin A deficiency decreased with age. This pattern can be better understood by considering several age-related physiological changes that affect nutritional status. Older adults experience reduced physiological function and physical activity due to muscle fiber losses [64] and lower bone mineral density [65]. These changes result in declined nitrogen retention, necessitating higher protein requirement to maintain muscle tissue [66]. Furthermore, many older adults may face “anorexia of aging” [67] caused by physiological, pathological, and social factors, leading to consequences such as PEM, sarcopenia, and frailty [68]. Age-related gastrointestinal changes such as impaired gastric motility and gastric acid secretion can affect nutrient absorption and worsen malnutrition [69]. Depression and dementia, common among older adults, also contribute to inadequate food intake [70, 71]. Vitamin A and iodine deficiencies may be more closely associated with regional, economic factors, and iodized salt use [61, 72] than with age.

The global age-standardised prevalence of iodine deficiency, vitamin A deficiency, and dietary iron deficiency demonstrated downward trends, mainly because of the increase in animal products consumption, dietary diversification, and improved access to micro-elements [73]. Furthermore, the inequality in the burden of PEM and iodine deficiency between high-income and low-income countries declined from 1990 to 2021, which indicates that global control and prevention of malnutrition have partly improved. However, cross-country inequalities still exist. Regionally, sub-Saharan Africa and South Asia suffer more from nutritional deficiencies. DALY rates of four nutritional deficiencies among the elderly were negatively correlated with the SDI scores. This difference may be due to geographical, cultural, economic, and demographic factors. In sub-Saharan Africa, rapid population growth, inefficient agriculture and industry, and inadequate public health awareness and healthcare system performance may cause malnutrition [74]. Diets with low red or processed meats and other healthy components (fruit, non-starchy vegetables, and legumes/nuts) in South Asia and sub-Saharan Africa may lead to these regional differences [75]. Another possible reason is that in low-income countries and regions, food insecurity is a contributor to malnutrition, with many older adults unable to safely access adequate and healthy foods due to low financial resources and high cost of living [76–78]. Studies from India [77] and sub-Saharan Africa [78] reported that vulnerable categories of older people at risk of food insecurity include those who are 80 years and older, those with lower socioeconomic positions, and those who are unmarried, divorced, or separated. Of additional concern is that in low- and middle-income countries, oral nutritional supplements are in scarce supply due to insufficient funding of nutritional care [79]. An ongoing scoping review on nutrition interventions for older people in Africa aims to synthesize evidence on effective strategies and engage local experts and communities to guide future interventions [80].

To address these nutritional challenges, comprehensive strategies are imperative, such as food fortification, nutritional education, micronutrient supplementation, and environmental sustainability. There are several promising initiatives that can be scaled up. For instance, in Austria, making malnutrition guidelines accessible to healthcare professionals enhances treatment rates [81]. Similarly, a quality improvement program in Colombia, which focused on nutrition for community-dwelling older adults, improved their nutritional status [82]. Oral nutritional supplements (ONS) have shown benefits in trials and systematic reviews, leading to increased body weight and fewer complications. The European Society for Clinical Nutrition and Metabolism (ESPEN) guidelines recommend offering ONS to older adults with malnutrition or at risk when food fortification and dietary counseling are insufficient [83].

The main strengths of this study include the long period of observation (1990–2021), the extensive geographic coverage (globally), and the large amount of data analysed. However, there are some limitations. First, GBD estimates are constrained by the quality of each country’s disease registration data, which often correlates with its socioeconomic status. In some low-income regions, the lack of high-quality data may introduce biases, potentially underestimating disease burden. While in some high-income countries, overestimations may occur due to reliance on data from major cities. GBD collaborators applied data cleaning, correction, and advanced statistical modeling to reduce the influence of these limitations. But this led to a new issue that findings rely heavily on modeled data, especially at the national level due to limited actual data. Additionally, GBD 2021 only collected data on PEM, iodine deficiency, vitamin A deficiency, and dietary iron deficiency. Other common nutritional deficiencies among older individuals, such as vitamin D and calcium deficiencies, were not included. Third, the GBD dataset does not provide direct data on medication use, co-morbidities and healthcare access among individuals with nutritional deficiencies, limiting our ability to conduct sensitivity analyses on these factors and explore their potential impact.

Conclusions

In summary, our study performed a comprehensive analysis of the burden of common nutritional deficiencies among the elderly population at global, regional, and national levels, using the latest GBD 2021 data. We revealed that although the global nutritional status among older adults has improved, the global prevalence of PEM demonstrated overall increasing trends in 1990 and 2021. Furthermore, cross-country health inequalities still exist. These results highlight the need for further investigation into the determinants of nutritional deficiencies among elderly individuals and the establishment of efficient prevention, management, and treatment programs, especially in countries/territories with low sociodemographic conditions.

Supplementary Information

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Supplementary Material 1

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Author contributions

S.L. and S.X. contributed equally to this manuscript. Conceptualization, S.L. and J. L.; methodology and statistical analysis, S.L. and G.T.; data curation, W.Z., X.G., C.Y. and C.Z.; writing—original draft preparation, S. L.; writing—review and editing, S.X. and G.C. All authors have read and agreed to the published version of the manuscript.

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Data availability

The data presented in this study are available in the Global Health Data Exchange GBD 2021 website at http://ghdx.healthdata.org/gbd-2021/sources.

Declarations

Institutional review board

For the utilising of deidentified data in GBD study, a waiver of informed consent has been approved by the University of Washington Institutional Review Board.

Informed consent

The institutions that conducted the surveys were responsible for obtaining informed consent from the participants.

Clinical trial number

not applicable.

Competing interests

The authors declare no competing interests.

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