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Global, regional and national burdens of nutritional deficiencies, from 1990 to 2019

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Abstract

The epidemiological and burden characteristics of nutritional deficiencies (ND) have been evolving, and it is crucial to identify geographical disparities and emerging trends. This study aimed to analyse the global, regional and national trends in the burden of ND over the past 30 years. Data were obtained from the Global Burden of Disease (GBD) 2019 database for the period 1990–2019. The study examined the incidence rates and disability-adjusted life years (DALY) of ND at various levels. Globally, the incidence rate of ND decreased from 2226·2 per 100 000 in 2019 to 2096·3 per 100 000 in the same year, indicating a decline of 5·8 %. The average annual percentage change (AAPC) was −0·21 (−0·31, −0·11). Similarly, DALY, prevalence and mortality rates of ND exhibited significant declines (AAPC = −3·21 (−3·45, −2·96), AAPC = −0·53 (−0·55, −0·51) and AAPC = −4·97 (−5·75, −4·19), respectively). The incidence rate of ND varied based on age group, sex, cause and geographical area. Moreover, a negative association was observed between incidence and the sociodemographic index. At the regional level, the South Asia and sub-Saharan Africa regions had the highest incidence rates of ND. In conclusion, the global incidence rate of ND showed a mixed pattern, while the DALY rate consistently declined. Additionally, prevalence and mortality rates of ND decreased between 1990 and 2019.

Keywords: **Nutritional deficiencies: Global burden of disease: Incidence: Disability-adjusted life years: Trend**

Nutritional deficiencies (ND), defined as inadequate intake or absorption of essential nutrients, are a critical global healthcare challenge with wide-ranging implications for individual growth and development[1,2]. They are a dynamic phenomenon that varies throughout life, and their negative impacts can have long-lasting or even permanent effects on cognition, motor performance, behaviour and overall health[3–6]. ND often play a causative role in the development of various diseases and can contribute to their undesirable progression[7–9]. It is worth noting that ND can predispose individuals to infectious and oncological complications, such as COVID-19[10,11].

Given the significant occurrence and outcomes associated with ND, various governments and organisations have put forth proposals to address this problem. For instance, the United Nations Decade of Action on Nutrition 2016–2025 and the Sustainable Development Goal aimed at 'eliminating all forms of malnutrition' highlight the need for comprehensive efforts to combat ND[12–14]. However, the world is moving away from the goal of ending hunger. A comprehensive exploration of global epidemiological patterns for ND and their complex disorders may be significant in evaluating the existing nutrition landscape and developing appropriate prevention practices.

In this work, we aimed to identify the global burden (incidence, disability-adjusted life years (DALY), prevalence and mortality) of ND based on The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2019. We also identified the years with the greatest change variability in trends for the noted factors. Finally, the global trends were further categorised with different variables (sex, age, cause and sociodemographic index (SDI)).

Methods

Data collection

The Global Burden of Disease (GBD) 2019 database is a global database with epidemiological data on 369 diseases from 1990 to 2019[15]. Given that the data released by the GBD database were

Abbreviations: AAPC, average annual percentage change; APC, annual percentage change; DALY, disability-adjusted life year; GBD, Global Burden of Disease; ND, nutritional deficiencies; SDI, sociodemographic index.

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publicly available, the present study did not require informed patient consent. Data stratified by age, sex, year and geographic area include the number and rate (per 100 000 population) of diverse factors (new cases, DALY, illnesses and deaths)[16]. Data collection was achieved through the Global Health Data Exchange (GHDx) query tool, which utilises multiple data sources such as censuses, disease registers and health service use data. The estimation methods include the Cause of Death Integration Model (CODEm), Spatio-Temporal Gaussian Process Regression (ST-GPR) and DisMod-MR tools[17]. Through the GBD database, researchers have access to up-to-date, detailed global epidemiological data on diseases that can help in disease burden assessment and decision-making. DALY is a measure of the overall health burden caused by a disease or health condition[18,19]. By combining Years Lived with Disability and Years of Life Lost, we can obtain the total number of DALY due to disease or health conditions for the entire population at a specific period.

Case definitions

Based on the International Classification of Diseases and Injuries, 10th revision (ICD-10), ND were categorised into five types: dietary Fe deficiency (ICD10 codes: D50~D50·9), iodine deficiency (ICD10 codes: E00~E02), protein-energy malnutrition (ICD10 codes: E40~E46·9 and E64·0), vitamin A deficiency (ICD10 codes: E50~E50·9 and E64·1) and other ND (ICD10 codes: D51~D53·9, E51~E61·9, E63~E64 and E64·2~E64·9)[20,21]. This classification system is widely recognised and used in the field of healthcare to classify and code diseases and health conditions. By utilising ICD-10 codes, we aimed to ensure consistency and comparability in our study. The five specific aetiologies (dietary Fe deficiency, iodine deficiency, protein-energy malnutrition, vitamin A deficiency and other ND) were selected based on their prevalence and significance in public health. Exclusion criteria were applied during the study design and data collection phases to ensure the validity and reliability of GBD findings. These criteria were based on the specific research objectives and aimed to minimise confounding factors. Meanwhile, it is important to provide information on the characteristics and health problems of the different age groups. The study population was divided into four age groups: 0–14, 15–49, 50–74 and 75+ years. The 0–14 age group usually covers the child and adolescent population, where there are specific health needs and developmental issues[22]. The 15–49 age group may be a critical period for fertility and reproductive health, while the 50–74 age group may have a high prevalence of common diseases in middle age and older age[23,24]. The 75 and older age group typically includes a higher risk of chronic disease and age-related health problems. Moreover, all countries and territories were divided into five parts, including low, low-middle, middle, high-middle and high SDI, based on a SDI from the Institute for Health Metrics and Evaluation (IHME)[25,26].

Statistical analysis

First, the age-specific rates and their average annual percentage changes (AAPC) were used to explore global trends in ND. AAPC, as a statistical indicator, was used to describe the change rate of a trend within a specific time interval based on the linear regression analysis[27]. By calculating the annual percentage change (APC) in a dataset, these APC are then weighted and averaged to give a single value that represents the average change rate across the time interval. AAPC is commonly applied to understand changes in trends and predict future directions. AAPC can signify the percentage change (increase, decrease or no change) from year to year. AAPC in multiple periods (1990–1999, 2000–2009, 2010–2019 and 1990–2019) were also accessed.

Next, we employed joinpoint regression analysis to identify trends in indicators over time and fitted the simplest model by adding joinpoints[28]. By analysing each joinpoint with the Monte Carlo permutation method, a final model was selected that best fit the data to identify the most significant years in the trend of change based on the Weighted Bayesian Information Criterion methods.

Finally, global trends were stratified by age group, sex, and SDI, and regional and national trends were also reported. The same AAPC methodology was used for all statistical analyses, and multiple software tools (R version 4.2.3 and Joinpoint Regression Program version 4.9.1.0) were used for data analysis and presentation of results. $P < 0{\cdot}05$ (two-sided) were deemed statistically significant[29].

Results

Global trends

Globally, the ND incidence generally decreased between 1990 and 2019 (AAPC = –0·21 (95 % CI –0·31, –0·11), with the most significant decreasing period occurring between 1990 and 1999 (AAPC = –0·36 (–0·39, –0·33), Table 1). Incidence counts of ND increased between 1990 and 2019; however, the changes in incident rates were positive. Altogether, the incident rate of ND decreased from 2226·2 (1850·4–2689·6) per 100 000 population in 1990 to 2096·3 (1766·1–2472·4) per 100 000 population in 2019, a decrease of 5·8 % (Table 2). The joinpoint regression determined a considerable change in the incidence of ND in 2005, 2010, 2014 and 2017 (Fig. 1). Meanwhile, DALY (AAPC = –3·21 (–3·45, –2·96)), prevalence (AAPC = –0·53 (–0·55, –0·51)) and mortality rate (AAPC = –4·97 (–5·75, –4·19)) of ND have decreased notably. The DALY, prevalence and mortality rate decreased by 60·8 %, 14·2 % and 76·8 % between 1990 and 2019, respectively (Table 2, online Supplementary Table S1).

Global trends by sex

Although female (AAPC = –0·36, $P < 0{\cdot}001$) incidence rates decreased between 1990 and 2019, a similar pattern has not been observed in male (AAPC = –0·07, $P = 0{\cdot}137$; Table 3). From 1990 to 2019, the incident cases among males and females increased by 41 % and 30·7 %, respectively, with an overarching trend of rising, falling and rising again (Table 2, Fig. 2). Meanwhile, the incident rates present a decreasing and then increasing trend for both sexes, with the trough located in 2015. Notably, the increasing trend in ND among males and females has become more pronounced since 2015 (Fig. 2).

Table 1. Global AAPC in prevalence, incidence, mortality and DALY of ND (95 % CI)

Period	Incidence			Prevalence			Mortality			DALY		
	AAPC	95 % CI	*P*	AAPC	95 % CI	*P*	AAPC	95 % CI	*P*	AAPC	95 % CI	*P*
1990–1999	−0·36	−0·39, −0·33	<0·001	−0·71	−0·74, −0·68	<0·001	−3·96	−4·62, −3·3	<0·001	−3·27	−3·81, −2·73	<0·001
2000–2009	−0·16	−0·26, −0·06	<0·001	−0·62	−0·66, −0·57	<0·001	−7·23	−9·53, −4·87	<0·001	−4·04	−4·57, −3·51	<0·001
2010–2019	−0·11	−0·4, −0·18	0·456	−0·28	−0·31, −0·26	<0·001	−3·92	−4·11, −3·73	<0·001	−2·28	−2·42, −2·13	<0·001
1990–2019	−0·21	−0·31, −0·11	<0·001	−0·53	−0·55, −0·51	<0·001	−4·97	−5·75, −4·19	<0·001	−3·21	−3·45, −2·96	<0·001

AAPC, average annual percentage change; DALY, disability-adjusted life years; ND, nutritional deficiencies.

Both the number and rate of DALY dropped dramatically, with lower declines for males than for females (AAPC − 3·55 (95 % CI − 3·15, −2·71) *v.* −2·93 95 % CI (−3·15, −2·71), Table 3). Similarly, the prevalence rate and mortality of ND fell markedly in both sexes, more so for males than for females (online Supplementary Table S3 and Fig. S1).

Global trends by age group

From 1990 to 2019, the incident rate in children and younger adolescents aged 0–14 years was remarkably greater than in other age groups, reaching 2670·3 per 100 000 population in 2019 (Table 2). Meanwhile, there is also a relatively high incident number among children and adolescents (Fig. 2). The incident trend showed a significant increase in all age groups apart from children and adolescents (AAPC = −0·14, $P = 0·006$; Table 3). The AAPC in the young adults (15–49 years), older adults (50–74 years) and older people (75+ years) groups were 1·05, 1·23 and 1·26, respectively (Table 3). However, the number of ND in children and adolescents (48554506 in 1990 to 52330896 in 2019), young adults (28453520 in 1990 to 56174614 in 2019), older adults (8 443 472 in 1990 to 24712546 in 2019) and older people (1 320 007 in 1990 to 4 488 917 in 2019) increased by 7·8 %, 97·4 %, 192·7 and 240·1, respectively (Table 2, Fig. 2).

The DALY numbers for the children and adolescents group have decreased, while the other groups have increased. The opposite trend was observed in the DALY rate (Table 2). Notably, the AAPC of DALY, prevalence and mortality in all age groups significantly dropped (Table 3, online Supplementary Table S2 and Fig. S1).

Global trends by causes

As presented in Table 2 and Fig. 2, vitamin A deficiency is the most predominant subtype of ND, with a decreasing trend in its incident number and incident rate from 1990 and 2019. Protein-energy malnutrition was another undesirable type of ND, with a serious global burden for DALY (Table 2, Fig. 2). The DALY rates decreased in all-cause subtypes, among which protein-energy malnutrition (985·9 in 1990 to 197·2 in 2019) declined most significantly by 80 % (Table 2). Additionally, the prevalence and deaths of different cause subtypes were presented in online Supplementary Table S1 and S2.

Global trends by sociodemographic index

The incidence rates of ND decreased in low (17·5 %) and low-middle SDI (22·3 %) areas while increasing in middle and above SDI areas (Table 2). Meanwhile, the AAPC for ND in middle, middle-high and high SDI areas was 0·81, 1·44 and 0·63 respectively, while the AAPC for ND in low and low-middle SDI areas was −0·88 and −0·68 (Table 3). Nevertheless, in 2019, the incident rate of ND per 100 000 population remains lower in middle and above SDI areas than in low or low-middle SDI areas. Moreover, the incident number of ND in 2019 has increased in all SDI regions compared with 1990 (Table 2).

DALY rates showed a decreasing direction in all SDI areas (Table 2), and the AAPC of incidence rate in all SDI areas were also decreasing (all AAPC < 0, all $P < 0·001$, Table 3). Notably,

Table 2. Incidence and DALY of ND at global and regional levels

	Incidence									
	No., 1990		No., 2019		No. change (%)	Rate 1990 (/10^5)		Rate 2019 (/10^5)		Rate change (%)
Global	119100916	98993857–143887601	162197527	136653964–191299880	36·2	2226·2	1850·4–2689·6	2096·3	1766·1–2472·4	–5·8
Sex										
Female	56092090	46329895–68634960	73336482	62109683–86022374	30·7	2111·8	1744·3–2584·1	1901·6	1610·5–2230·6	–10
Male	63008825	52536241–76085024	88861046	74392565–105463458	41	2339·1	1950·3–2824·5	2289·7	1916·9–2717·4	–2·1
Age (years)										
0–14	48554506	45694003–52168822	52330896	48025169–57716774	7·8	2768·3	2605·2–2974·3	2670·3	2450·6–2945·1	–3·5
15–49	28453520	22976506–35746479	56174614	45329045–70552538	97·4	1049·1	847·2–1318	1427·5	1151·9–1792·9	36·1
50–74	8 443 472	6 703 400–10336043	24712546	19446280–30511883	192·7	1101·3	874·4–1348·2	1578	1241·8–1948·4	43·3
75+	1 320 007	1 014 237–1 659 250	4 488 917	3 412 420–5 724 572	240·1	1127·9	866·6–1417·8	1623	1233·8–2069·7	43·9
Cause										
Dietary Fe deficiency	0	0–0	0	0–0	NA	0	0–0	0	0–0	NA
Iodine deficiency	7 711 749	6 265 218–9 349 772	8 111 508	6 500 143–9 966 057	5·2	144·1	117·1–174·8	104·8	84–128·8	–27·3
Other ND	0	0–0	0	0–0	NA	0	0–0	0	0–0	NA
Protein-energy malnutrition	111389167	91268425–136380189	154086019	128445223–183279047	38·3	2082·1	1706–2549·2	1991·4	1660–2368·7	–4·4
Vitamin A deficiency	877376295	840347028–914976465	489662709	469006374–512234291	–44·2	16 400	15 707·9–17 102·9	6328·5	6061·5–6620·2	–61·4
SDI										
High-middle	7 276 517	5 964 657–8 821 153	10845728	8 773 025–13098262	49·1	885·2	725·6–1073·1	1070·2	865·7–1292·5	20·9
High	11770875	9 975 302–14168351	22294079	18224647–27126083	89·4	1023·2	867·1–1231·6	1558·6	1274·1–1896·4	52·3
Low-middle	13769154	12900074–14849368	22852411	20865622–25426217	66	2607·1	2442·5–2811·6	2024·7	1848·7–2252·7	–22·3
Low	29595898	27168207–32685316	38142885	33348332–44541076	28·9	2619·9	2405–2893·4	2162·3	1890·5–2525	–17·5
Middle	24817909	21616005–29018711	43941882	37056080–52709211	77·1	1445·6	1259·1–1690·3	1833·5	1546·2–2199·4	26·8
Region										
Andean Latin America	275 990	241 350–313 904	377 625	332 461–431 579	36·8	722·9	632·2–822·2	593·8	522·8–678·6	–17·9
Australasia	101 595	85 123–122 118	166 503	138 737–199 068	63·9	501	419·8–602·2	572·9	477·4–684·9	14·4
Caribbean	403 462	333 913–485 097	422 723	356 807–499 164	4·8	1143·8	946·6–1375·2	896·2	756·5–1058·3	–21·6
Central Asia	703 552	595 028–843 428	802 198	674 819–960 613	14	1015·7	859–1217·7	857·7	721·5–1027·1	–15·6
Central Europe	894 782	702 387–1 118 547	944 062	754 100–1 170 503	5·5	727·7	571·2–909·6	826·5	660·2–1024·7	13·6
Central Latin America	2 339 702	1 982 059–2 755 385	2 975 636	2 483 002–3 527 054	27·2	1425·6	1207·7–1678·9	1190·2	993·1–1410·7	–16·5
Central Sub-Saharan Africa	1 855 710	1 529 910–2 261 595	2 746 499	2 373 993–3 206 242	48	3342·4	2755·6–4073·5	2087·9	1804·7–2437·4	–37·5
East Asia	20146456	15382935–26369892	29341667	23187621–36344215	45·6	1644·4	1255·6–2152·4	1993	1575–2468·7	21·2
Eastern Europe	1 598 906	1 311 442–1 934 824	1 539 084	1 223 373–1 896 299	–3·7	705·9	579–854·2	733	582·6–903·1	3·8
Eastern Sub-Saharan Africa	5 113 069	4 193 513–6 339 469	7 142 597	6 072 122–8 380 019	39·7	2688·7	2205·2–3333·6	1734·6	1474·6–2035·1	–35·5
High-income Asia Pacific	1 148 722	958 522–1 382 369	1 323 670	1 075 415–1 613 426	15·2	662	552·4–796·7	706·7	574·2–861·5	6·8
High-income North America	1 954 927	1 541 789–2 443 335	3 072 006	2 418 972–3 776 253	57·1	695·9	548·8–869·7	842·7	663·5–1035·8	21·1
North Africa and Middle East	6 392 740	5 295 931–7 803 246	9 359 303	8 040 842–10846679	46·4	1852·8	1534·9–2261·6	1537·6	1321–1781·9	–17
Oceania	146 029	119 239–182 720	267 590	214 799–331 684	83·2	2257·1	1843–2824·2	2015·5	1617·9–2498·3	–10·7
South Asia	51014128	43090664–61007431	66381377	55381877–78770018	30·1	4647·7	3925·8–5558·1	3677·2	3067·9–4363·5	–20·9
Southeast Asia	13068191	10878824–15755895	16813154	14213233–19563548	28·7	2799·6	2330·6–3375·4	2495·3	2109·5–2903·5	–10·9
Southern Latin America	358 520	303 948–422 954	605 049	501 197–727 121	68·8	723·7	613·5–853·7	906·4	750·8–1089·3	25·2
Southern Sub-Saharan Africa	721 116	607 342–876 342	842 428	716 190–992 425	16·8	1373·7	1157–1669·4	1072·1	911·5–1263	–22
Tropical Latin America	1 210 380	986 379–1 483 967	1 439 938	1 206 775–1 712 146	19	791·7	645·2–970·7	644	539·7–765·7	–18·7
Western Europe	4 439 749	3 657 274–5 447 233	6 221 989	5 080 799–7 541 776	40·1	1154·4	950·9–1416·4	1426·1	1164·5–1728·5	23·5
Western Sub-Saharan Africa	5 213 190	4 226 168–6 529 639	9 412 428	8 157 715–11017349	80·6	2707	2194·5–3390·6	2062·7	1787·7–2414·4	–23·8

Table 2. (*Continued*.)

	DALY								
	No., 1990		No., 2019		No. change (%)	Rate 1990 (/10^5)		Rate 2019 (/10^5)		Rate change (%)
Global	87847408	69856803–111925183	49775124	36889950–65839422	–43·3	1642·1	1305·8–2092·1	643·3	476·8–850·9	–60·8
Sex										
Female	46388584	33318803–62520514	28456555	21132186–37721021	–38·7	1746·5	1254·4–2353·8	737·9	548–978·1	–57·7
Male	41458824	33665854–50453511	21318569	16030317–27817401	–48·6	1539·1	1249·8–1873	549·3	413–716·8	–64·3
Age (years)										
0–14	67004080	52751021–86643264	26339578	20235568–33595123	–60·7	3820·1	3007·5–4939·8	1344	1032·6–1714·2	–184·2
15–49	13310246	9 566 292–18078244	14322502	9 731 752–20090519	7·6	490·8	352·7–666·6	364	247·3–510·5	–25·8
50–74	6 166 867	4 672 969–7 984 295	7 223 933	5 248 758–9 675 620	17·1	425·7	322·5–551·1	245·3	178·2–328·5	–42·4
75+	1 366 215	1 107 323–1 644 849	1 889 111	1 562 613–2 326 713	38·3	790·8	641–952·1	443·3	366·7–546	–43·9
Cause										
Dietary Fe deficiency	25069790	16835783–36058206	28534680	19127591–41139284	13·8	468·6	314·7–674	368·8	247·2–531·7	–21·3
Iodine deficiency	2 499 955	1 534 318–4 033 663	2 438 599	1 372 657–4 238 613	–2·5	46·7	28·7–75·4	31·5	17·7–54·8	–32·5
Other ND	5 566 372	3 545 372–7 693 399	2 367 814	1 879 522–2 950 809	–57·5	104	66·3–143·8	30·6	24·3–38·1	–70·6
Protein-energy malnutrition	52743908	40250363–70481552	15256524	12565114–18327803	–71·1	985·9	752·4–1317·4	197·2	162·4–236·9	–80
Vitamin A deficiency	1 967 383	1 362 752–2 795 113	1 177 507	805 056–1 636 582	–40·1	36·8	25·5–52·2	15·2	10·4–21·2	–58·7
SDI										
High-middle	5 641 095	4 216 113–7 503 141	1 456 034	1 049 926–1 973 130	–74·2	188	129·9–262	143·7	103·6–194·7	–23·6
High	1 545 153	1 067 509–2 153 516	3 777 225	2 628 068–5 243 542	144·5	490·3	366·5–652·2	264·1	183·7–366·6	–46·1
Low-middle	38381607	28444221–50860085	18299217	14184880–23321623	–52·3	4949·4	3981·4–6377·7	1621·3	1256·8–2066·3	–67·2
Low	26139782	21027530–33683100	16197717	11889740–21765779	–38	3397·7	2518–4502·3	918·2	674–1233·9	–73
Middle	16099695	12945701–20206540	10018418	7 136 818–13547619	–37·8	937·8	754·1–1177	418	297·8–565·3	–55·4
Region										
Andean Latin America	653 310	546 236–780 019	240 935	179 774–317 266	–63·1	1711·3	1430·8–2043·2	378·9	282·7–498·9	–77·9
Australasia	24 867	16 461–37 475	25 809	17 292–36 906	3·8	122·6	81·2–184·8	88·8	59·5–127	–27·6
Caribbean	523 710	412 459–669 429	292 017	220 700–380 301	–44·2	1484·7	1169·3–1897·8	619·1	467·9–806·3	–58·3
Central Asia	502 901	353 263–697 873	466 713	310 559–663 201	–7·2	726	510–1007·5	499	332–709·1	–31·3
Central Europe	335 495	222 099–481 486	193 281	129 245–277 703	–42·4	272·8	180·6–391·6	169·2	113·2–243·1	–38
Central Latin America	1 645 199	1 449 248–1 886 605	768 753	612 602–963 123	–53·3	1002·4	883–1149·5	307·5	245–385·2	–69·3
Central Sub-Saharan Africa	2 783 190	2 030 245–3 858 035	1 739 853	1 284 272–2 316 849	–37·5	5013	3656·8–6948·9	1322·6	976·3–1761·3	–73·6
East Asia	7 297 459	5 812 959–9 226 732	2 736 622	1 906 356–3 833 472	–62·5	595·6	474·5–753·1	185·9	129·5–260·4	–68·8
Eastern Europe	551 271	383 060–776 640	379 716	258 871–546 433	–31·1	243·4	169·1–342·9	180·8	123·3–260·2	–25·7
Eastern Sub-Saharan Africa	11832134	9 543 220–15180255	6 298 676	4 988 236–7 823 056	–46·8	6222	5018·4–7982·6	1529·6	1211·4–1899·8	–75·4
High-income Asia Pacific	537 633	360 263–786 927	317 743	215 860–455 273	–40·9	309·9	207·6–453·5	169·7	115·3–243·1	–45·2
High-income North America	316 133	222 888–428 586	443 235	322 522–601 267	40·2	112·5	79·3–152·6	121·6	88·5–164·9	8·1
North Africa and Middle East	3 022 827	2 200 940–4 448 876	2 136 443	1 525 524–2 983 497	–29·3	876·1	637·9–1289·4	351	250·6–490·1	–59·9
Oceania	63 875	47 608–83 655	96 887	68 688–133 223	51·7	987·3	735·8–1293	729·8	517·4–1003·5	–26·1
South Asia	42043737	30639129–55964842	20946037	14876928–28637410	–50·2	3830·4	2791·4–5098·7	1160·3	824·1–1586·4	–69·7
Southeast Asia	5 727 002	4 466 977–7 426 074	3 162 732	2 361 354–4 261 032	–44·8	1226·9	957–1590·9	469·4	350·5–632·4	–61·7
Southern Latin America	208 293	163 454–269 448	132 057	97 091–180 802	–36·6	420·4	329·9–543·9	197·8	145·4–270·9	–52·9
Southern Sub-Saharan Africa	887 613	722 902–1 077 314	632 595	498 189–787 208	–28·7	1690·9	1377·1–2052·3	805·1	634–1001·9	–52·4
Tropical Latin America	1 967 557	1 621 313–2 370 941	971 908	711 188–1 356 678	–50·6	1287	1060·5–1550·8	434·7	318·1–606·8	–66·2
Western Europe	650 451	445 993–890 965	667 370	470 188–896 059	2·6	169·1	116–231·7	153	107·8–205·4	–9·5
Western Sub-Saharan Africa	6 272 748	5 015 144–7 809 590	7 125 742	5 449 404–9 185 621	13·6	3257·2	2604·2–4055·2	1561·6	1194·2–2013	–52·1

DALY, disability-adjusted life years; ND, nutritional deficiencies; SDI, sociodemographic index.

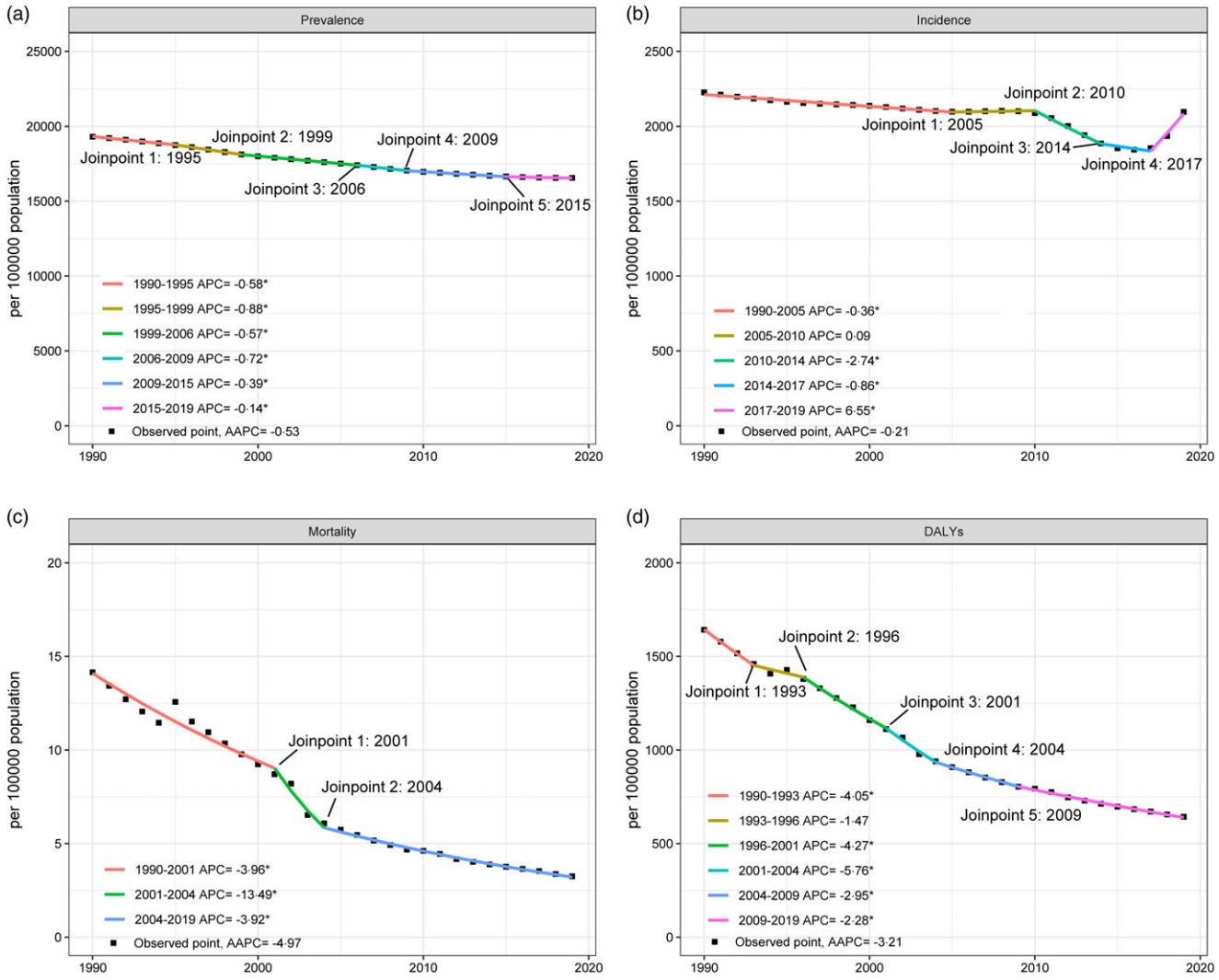

Fig. 1. Joinpoint regression analysis of global trend for ND from 1990 to 2019. (a) Prevalence, (b) incidence, (c) mortality and (d) DALY. ND, nutritional deficiencies; DALY, disability-adjusted life years.

the high SDI area was the only area where the incident number of ND increased (144·5 %, Table 2). Similarly, prevalence rates indicated a decreasing direction in all SDI areas; the middle-high SDI area is the only area with increased mortality (online Supplementary Table S1).

Regional trends

The incident number of ND is increasing in all regions except Eastern Europe from 1990 to 2019 (Table 2). And South Asia demonstrated the greatest incident number (66381377 (95 % CI 55381877, 78770018)) and incident rate (3677·2 (95 % CI 3067·9, 4363·5) per 100 000 population) of ND in 2019. However, ND have increased the most in Oceania (83·2 %), from 146 029 in 1990 to 267 590 in 2019 (Table 2). And an increase in incident rates was observed primarily in Southern Latin America (25·2 %). The joinpoint regression analysis demonstrated that only five of all regions presented a clear rise in incident rate, namely Australasia (AAPC = 1·22), Central Europe (AAPC = 2·88), High-income Asia Pacific (AAPC = 2·2), High-income North America (AAPC = 1·7) and Western Europe (AAPC = 2·11, Table 3).

Five regions (Australasia, High-income North America, Oceania, Western Europe and Western Sub-Saharan Africa) have experienced an increase in the DALY number in the past 30 years, and the only region where the DALY rate has increased is High-income North America (8·1 %, Table 2). Moreover, the DALY rate declined in the majority of these regions from 1990 to 2019 (AAPC < 0, $P < 0{\cdot}001$, Table 3), most notably in Central Sub-Saharan Africa (AAPC = –1·58) and Eastern Sub-Saharan Africa (AAPC = –1·51). The regional prevalence and mortality were demonstrated in online Supplementary Table S1 and Table S2.

National trends

As shown in Fig. 3, the highest incident rates of ND in 2019 were in Maldives (4802·7 (95 % CI 3936·3, 5785·3) per 100 000 population), Sri Lanka (4679·5 (95 % CI 3851·1, 5635·8) per 100 000 population) and India (4030·4 (95 % CI 3323·1, 4817) per

Table 3. Subgroups AAPC in incidence and DALY of ND (95 % CI)

	Incidence			DALY		
	AAPC	95 % CI	*P*	AAPC	95 % CI	*P*
Global	−0·21	−0·31, −0·11	<0·001	−3·21	−3·45, −2·96	<0·001
Sex						
Female	−0·36	−0·44, −0·28	<0·001	−2·93	−3·15, −2·71	<0·001
Male	−0·07	−0·17, 0·02	0·137	−3·55	−3·86, −3·24	<0·001
Age (years)						
0–14	−0·14	−0·24, −0·04	0·006	−3·53	−3·75, −3·31	<0·001
15–49	1·05	0·97, 1·13	<0·001	−1·03	−1·27, −0·79	<0·001
50–74	1·23	1·1, 1·36	<0·001	−1·95	−2·71, −1·19	<0·001
75+	1·26	1·21, 1·32	<0·001	−2	−2·77, −1·21	<0·001
Cause						
Protein-energy malnutrition	−0·15	−0·34, 0·03	0·108	−5·36	−5·69, −5·03	<0·001
Iodine deficiency	−1·1	−1·15, −1·05	<0·001	−1·35	−1·43, −1·27	<0·001
Vitamin A deficiency	−3·24	−3·4, −3·08	<0·001	−3	−3·03, −2·96	<0·001
Dietary Fe deficiency	NA		NA	−0·82	−0·84, −0·81	<0·001
Other ND	NA		NA	−4·22	−4·55, −3·89	<0·001
SDI						
High	0·63	0·6, 0·66	<0·001	−0·93	−1·08, −0·79	<0·001
High-middle	1·44	1·2, 1·69	<0·001	−2·12	−2·22, −2·02	<0·001
Low	−0·88	−0·97, −0·78	<0·001	−3·8	−3·94, −3·65	<0·001
Low-middle	−0·68	−0·89, −0·46	<0·001	−4·46	−5·01, −3·9	<0·001
Middle	0·81	0·53, 1·1	<0·001	−2·76	−2·86, −2·67	<0·001
Region						
Andean Latin America	−4·5	−4·71, −4·29	<0·001	−0·71	−0·79, −0·64	<0·001
Australasia	1·22	0·98, 1·46	<0·001	0·49	0·3, 0·68	<0·001
Caribbean	−4·11	−4·33, −3·9	<0·001	−0·87	−1, −0·75	<0·001
Central Asia	−4·65	−5·02, −4·27	<0·001	−0·62	−0·83, −0·42	<0·001
Central Europe	2·88	2·49, 3·26	<0·001	0·43	0·33, 0·52	<0·001
Central Latin America	−3·59	−3·88, −3·31	<0·001	−0·65	−0·76, −0·53	<0·001
Central Sub-Saharan Africa	−6·03	−6·14, −5·93	<0·001	−1·58	−1·82, −1·35	<0·001
East Asia	−3·77	−10·18, 3·1	0·275	0·64	0·49, 0·79	<0·001
Eastern Europe	−0·76	−1·63, 0·13	0·093	0·11	−0·02, 0·24	0·111
Eastern Sub-Saharan Africa	−5·72	−6·22, −5·22	<0·001	−1·51	−1·57, −1·45	<0·001
High-income Asia Pacific	2·2	1·77, 2·63	<0·001	0·2	0·14, 0·26	<0·001
High-income North America	1·7	1·37, 2·04	<0·001	0·62	0·52, 0·71	<0·001
North Africa and Middle East	−5·38	−5·54, −5·22	<0·001	−0·67	−0·72, −0·62	<0·001
Oceania	−2·39	−2·77, −2	<0·001	−0·52	−0·74, −0·3	<0·001
South Asia	−8·41	−8·64, −8·19	<0·001	−0·83	−1·01, −0·64	<0·001
Southeast Asia	−3·01	−3·08, −2·95	<0·001	−0·4	−0·72, −0·08	<0·001
Southern Latin America	−0·19	−0·61, 0·23	0·38	0·74	0·64, 0·84	0·015
Southern Sub-Saharan Africa	−2·82	−3·19, −2·45	<0·001	−0·87	−1·04, −0·7	<0·001
Tropical Latin America	−3·52	−3·73, −3·31	<0·001	−0·75	−0·85, −0·66	<0·001
Western Europe	2·11	1·89, 2·33	<0·001	0·71	0·66, 0·75	<0·001
Western Sub-Saharan Africa	−4·12	−4·44, −3·79	<0·001	−0·95	−1·11, −0·78	<0·001

AAPC, average annual percentage change; DALY, disability-adjusted life years; ND, nutritional deficiencies; SDI, sociodemographic index.

100 000 population). Meanwhile, the most predominant increase in ND's incident rate from 1990 to 2019 was observed in Czechia (AAPC = 2·2, $P < 0·001$). There has been an over 200 % rise in the incident number in three countries – Qatar (482 %), the United Arab Emirates (266·1 %) and Afghanistan (215·2 %) nearly 30 years (online Supplementary Fig. S2).

Evidently, the country with the greatest DALY rate for ND in 2019 was Mali (6770·1 (95 % CI 4916, 9285) per 100 000 population; Fig. 4). Of the 204 countries and territories, only a few have recorded an increase in DALY rates from 1990 to 2019, while others have recorded a decrease or no significant change. These countries with increased DALY rates were Belgium (AAPC = 0·42, $P < 0·001$), Norway (AAPC = 0·36, $P < 0·001$), the USA (AAPC = 0·29, $P < 0·001$) and France (AAPC = 0·02, $P < 0·001$), respectively. And Qatar presented the largest increase in the DALY rate (170·6 %) between 1990 and 2019 (online Supplementary Fig. S2). Furthermore, the additional information for the prevalence and mortality of ND between 1990 and 2019 was presented in online Supplementary Fig. S3–S5.

Trends between ND and SDI

Globally, incidence, DALY, prevalence and mortality presented a striking negative association with SDI ($R < 0$, $P < 0·001$; Fig. 5, online Supplementary Fig. S6). The incidence of ND was clearly superior in lower SDI areas, particularly in sub-Saharan Africa (Fig. 5). And the greatest incident rate was observed in South Asia; correspondingly, Maldives, Sri Lanka and India were also observed to have the highest incidence of ND (Fig. 5). The DALY rate has been declining across all regions annually, with lower SDI regions declining more rapidly, and the similar landscape was observed in the relationship between prevalence rate and

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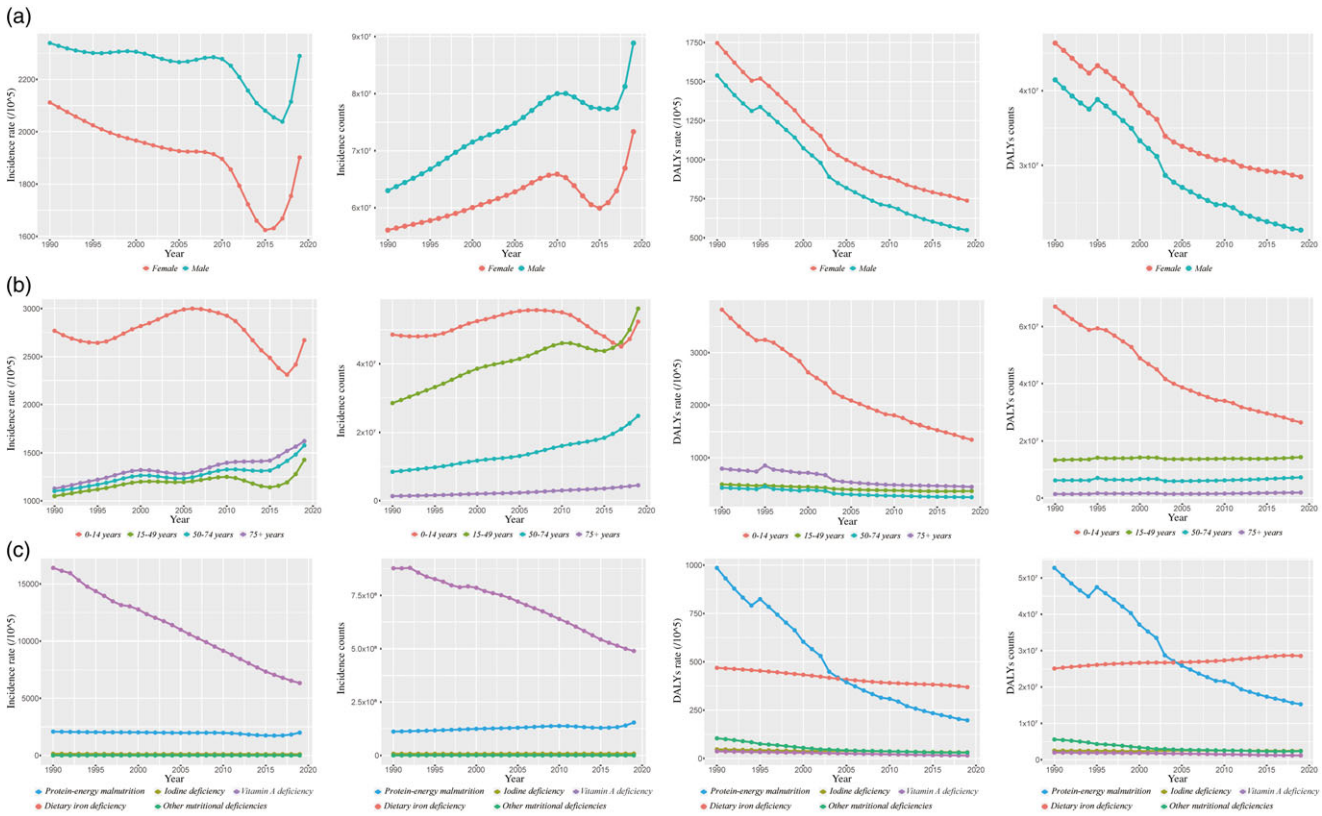

Fig. 2. Incidence and DALY of ND in subgroups from 1990 to 2019. (a) Sex, (b) age and (c) causes. DALY, disability-adjusted life years; ND, nutritional deficiencies.

SDI. Furthermore, as the low SDI regions, sub-Saharan Africa and South Asia presented the highest mortality rates for ND (online Supplementary Fig. S6).

Discussion

To date, this is the first research to discuss changes in the incidence, DALY, prevalence and mortality of ND from 1990 to 2019 at global, regional and national levels. The incident rates of ND showed a falling–rising trend, while the DALY rates have declined in the past 30 years. And the enormous incidence number of ND shows that it remains an inescapable global threat. Meanwhile, the incident rates of ND for males are significantly greater than for females, and there is a significant increase in incidence in all age groups (AAPC > 0) except for children and younger adolescents aged 0–14 years. For available aetiology, the incident rate has decreased since 1990. We also observed a negative association between SDI and incident rates. Interestingly, except for low and low-middle SDI areas, the incident rate has increased in other areas. Reassuringly, DALY, prevalence and mortality rates are largely dropping for all sexes, ages, causes and regions (AAPC < 0), albeit to varying degrees.

The number of people suffering from ND is growing in parallel with the global population, and all countries and territories continue to struggle with any form of ND[30]. Incident numbers of ND increased from 119100916 in 1990 to 162197527 in 2019, an increase of 36·2 %. The risk of ND is greatest in males, infants, children and adolescents. The majority of child deaths are directly or indirectly attributable to ND worldwide[31]. For children and younger adolescents aged 0–14 years, the incidence, DALY, prevalence and mortality rates of ND in 2019 were all decreasing compared with 1990, and this finding was closely aligned with persistent investment in this cohort worldwide. Encouragingly, there is a downward trend in mortality for all age subgroups, and a similar trend was observed in both sexes. Not only is it perfectly feasible to improve nutrition, but it is also sustainable and cost-effective. However, the emergence of diverse crises, including wars, epidemics and droughts, is creating the conditions for a significant increase in severe global ND[32].

Also, national and regional differences were observed in the popularisation of ND. Nationally, developing countries are the areas most affected by ND, and the morbidity of ND in India was markedly higher than in other countries. Severe ND lead to a weakened immune function[33,34], and this phenomenon may be responsible for the prevalence of infectious diseases in India. We found that DALY and deaths associated with ND are particularly common in Mali. At the national level, nutrition interventions are one of the optimal development investments every country can make. However, this initiative is constrained by various factors, such as economic status, political stability or climate change[35–37]. Regionally, we observed that the incidence of ND is highest in Asia, but fastest growing in Africa. South Asia remains the 'hardest hit' by ND, with about 3677 per 100 000 population, almost three times as many as in sub-Saharan Africa.

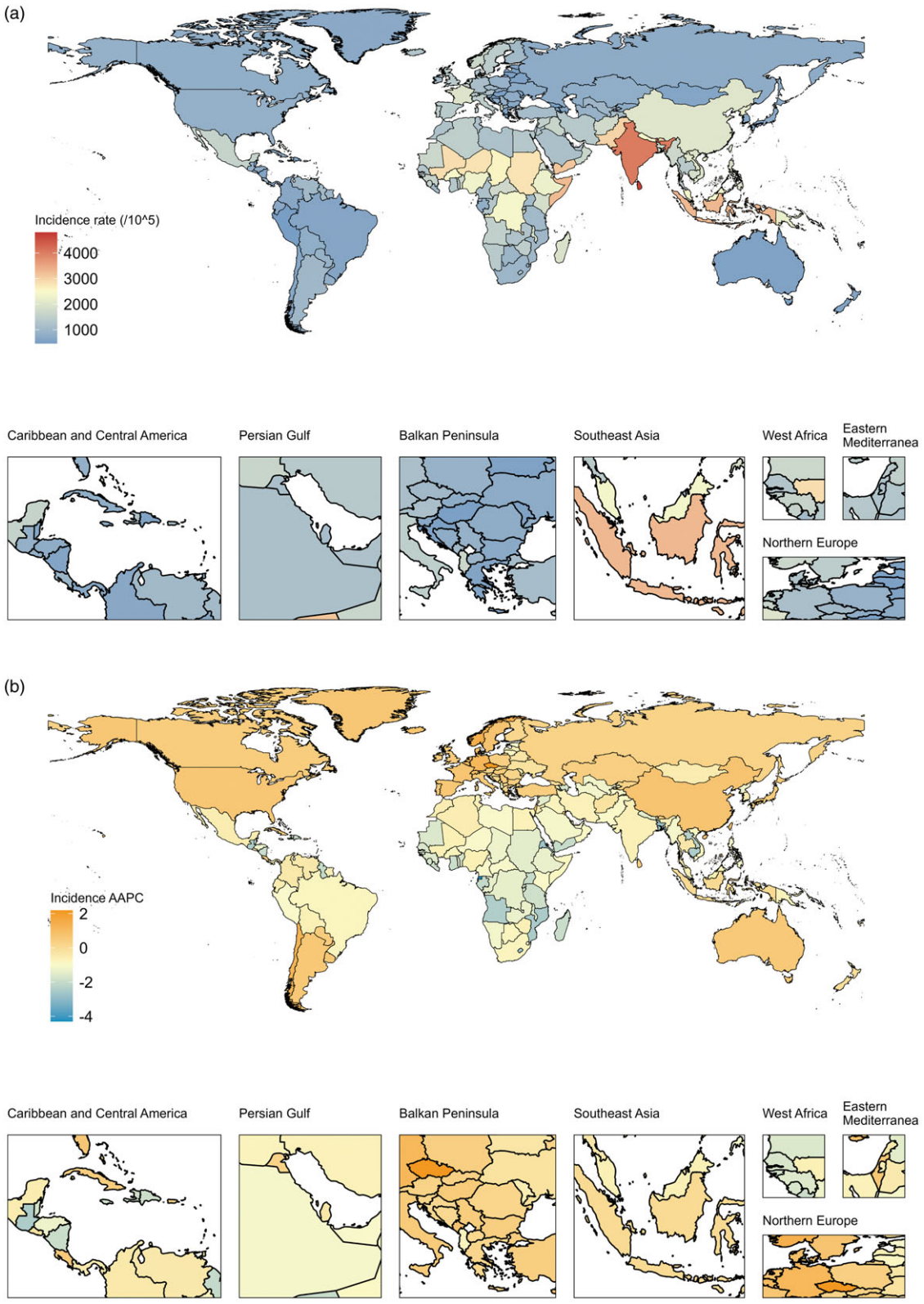

Fig. 3. Geographical distribution of ND incidence in 204 countries and territories. (a) Incidence rate of ND in 2019, (b) AAPC in incidence rate of ND between 1990 and 2019. AAPC, average annual percentage change; ND, nutritional deficiencies.

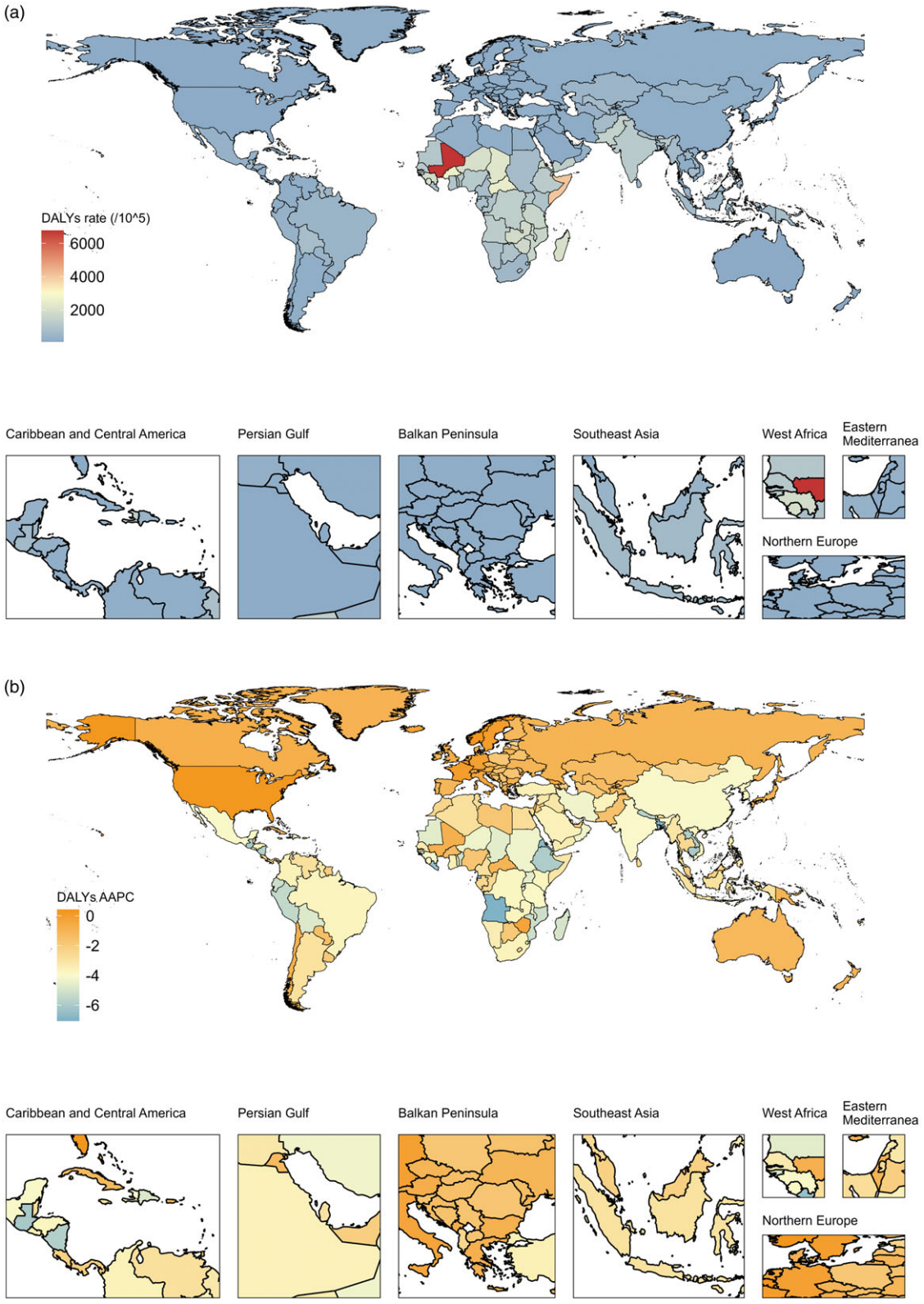

Fig. 4. Geographical distribution of ND DALY in 204 countries and territories. (a) DALY rate of ND in 2019, (b) AAPC in DALY rate of ND between 1990 and 2019. ND, nutritional deficiencies; DALY, disability-adjusted life years; AAPC, average annual percentage change.

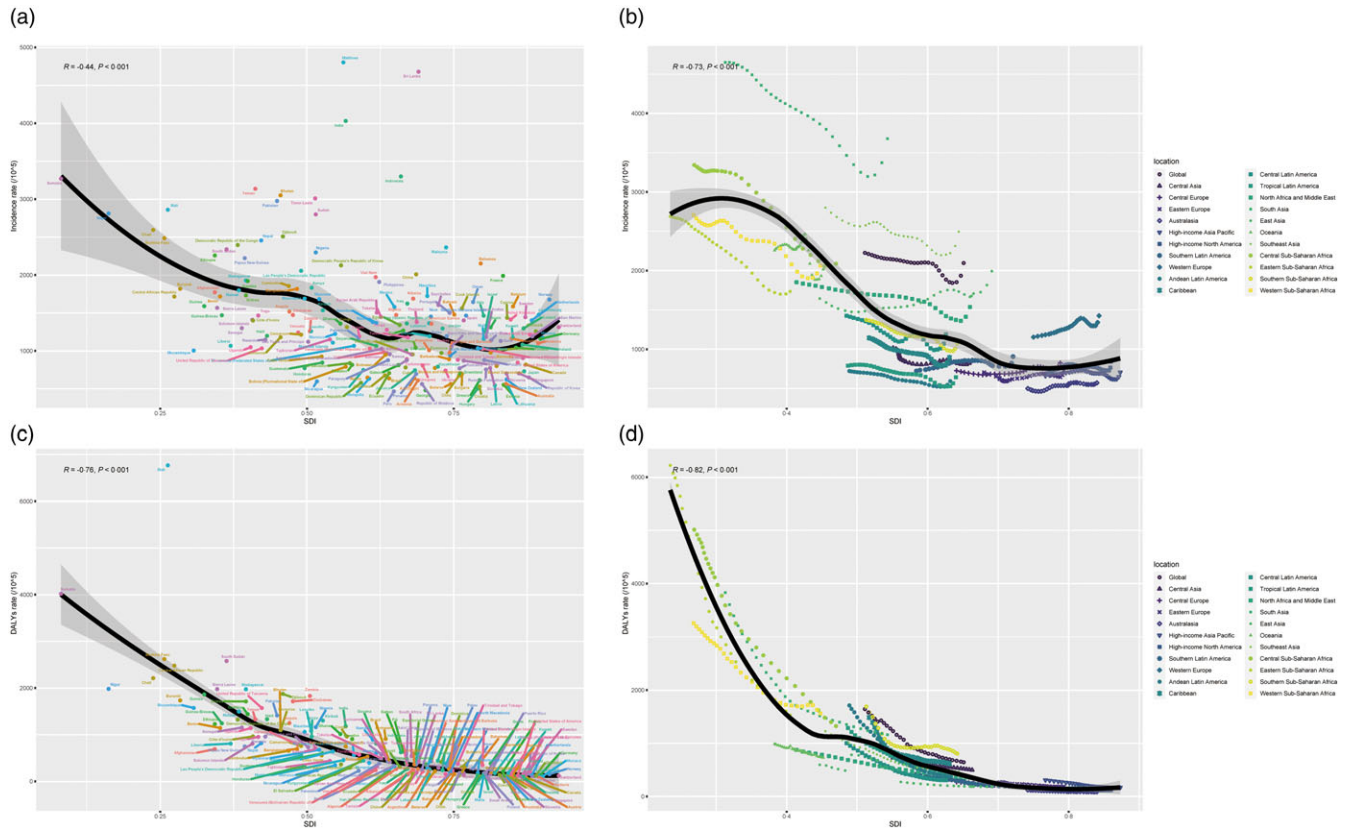

Fig. 5. Global, twenty-one regions, and 204 countries and territories burden of ND by SDI, from 1990 to 2019. (a) Incidence per 100 000 population in global and 204 countries and territories, (b) incidence per 100 000 population in global and twenty-one regions, (c) DALY per 100 000 population in global and 204 countries and territories and (d) DALY per 100 000 population in global and twenty-one regions. For each region, points from left to right depict estimates from each year from 1990 to 2019. ND, nutritional deficiencies; SDI, sociodemographic index; DALY, disability-adjusted life years.

Meanwhile, it is notable that ND in Asia and Africa indicate a significant year-on-year decrease. Poverty exacerbates the development of ND, and people living in poverty (low or low-middle SDI areas) are more likely to be affected by ND. Additionally, ND increase healthcare costs, reduce productivity and slow economic growth, which can create a vicious cycle between poverty and poor health status[38,39]. This dilemma is likely to become even more serious with the popularisation of COVID-19 in 2019.

This study provides some insights for future exploration. The 'Zero Hunger' goal involves not only ensuring that people have adequate energy intake but also that their diets meet nutritional requirements and avoid malnutrition. Prior reports have demonstrated that with the persistence of ND, this goal by 2030 will be difficult to achieve[40,41]. It is essential to discover temporal trends in the global burden of ND, thus indicating the effectiveness of existing nutrition promotion strategies and strengthening guidance to global organisations to control ND. There is evidence that no single natural food can satisfy all the energy and nutrient needs of the body, making the timely use of nutritional supplements valuable[42,43]. It is necessary to conduct a scientific review of the application of nutrient supplements in different cohorts to reveal the optimal schemes. For further work, a global shift towards a healthy diet, based on the principle of sustainable development, will help to prevent the spread of ND and bring about significant savings.

In response to the burden of ND, various policies and actions have been implemented in the area of nutritional healthcare. These efforts aim to improve the availability, accessibility and affordability of nutritious food and to strengthen nutrition education and counselling. Interventions such as fortification of staple foods, promotion of breast-feeding and implementation of school feeding programmes have also been initiated to address specific ND[44]. It is also recognised that the use of dietary supplements can be valuable in meeting the energy and nutrient needs of individuals, especially when natural food sources are inadequate[45]. However, it is important to conduct a scientific review of the use of dietary supplements in different populations to determine the best options. This requires an assessment of the efficacy, safety and cost-effectiveness of different supplementation strategies, taking into account factors such as age, sex and specific ND.

Inevitably, there are some limitations to our study. First, this study is restricted by collected variables and missing data in GBD, particularly the aetiological category. Data on poorer areas may be underestimated due to the lack of efficient statistical instruments. Second, additional factors may influence the development of ND, such as educational resources, climate change and national security, which were not included in this study. Finally, the results of this study have not been validated by external comparative studies. To address the limitations mentioned, future research should focus on improving GBD

data quality by addressing regional discrepancies and implementing standardised data collection protocols and training programmes. Additionally, research should explore emerging trends in ND aetiology and management, including the impact of climate change on food availability and nutritional value, as well as the effects of educational resources and national security on ND prevalence and management.

Conclusions

Overall, the global incidence rate of ND presents a decreasing and then increasing trend, while DALY, prevalence and mortality present a significant decreasing trend. Meanwhile, specific populations, such as males, adolescents aged 0–14 years, or populations in low SDI areas, should be given priority attention to control this adverse event. Adequate will and funding are urgently necessary to ensure the best investment in health and development for the population with ND.

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All authors contributed to the study's conception and design. X. Q. performed data collection and analysis. X. Q. and Y. J. wrote the manuscript. K. W., K. X. and C. Y. polished and revised the manuscript. All authors commented on previous versions of the manuscript and read and approved the final manuscript.

The authors declare that they have no competing interests.

Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114524001272

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