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

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Abbreviations: APC: annual percentage change; AAPC: average annual percentage change; CODEm: Cause of Death Integration Model; DALYs: disability-adjusted life year; GBD: Global Burden of Disease; GHDx: Global Health Data Exchange; ICD-10: International Classification of Diseases and Injuries, 10th revision; IHME: Institute for Health Metrics and Evaluation; NDs: nutritional deficiencies; ST-GPR: Spatio-Temporal Gaussian Process Regression; YLDs: Years Lived with Disability; YLLs: Years of Life Lost; SDI: socio-demographic index.

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Abstract

The epidemiological and burden characteristics of nutritional deficiencies (NDs) have been evolving, and it is crucial to identify geographical disparities and emerging trends. This study aimed to analyze the global, regional, and national trends in the burden of NDs 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 (DALYs) of NDs at various levels. Globally, the incidence rate of NDs 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 to -0.11). Similarly, DALYs, prevalence, and mortality rates of NDs exhibited significant declines (AAPC = -3.21 [-3.45 to -2.96], AAPC = -0.53 [-0.55 to -0.51], and AAPC = -4.97 [-5.75 to -4.19], respectively). The incidence rate of NDs varied based on age group, gender, 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 NDs. In conclusion, the global incidence rate of NDs showed a mixed pattern, while the DALY rate consistently declined. Additionally, prevalence and mortality rates of NDs decreased between 1990 and 2019.

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

Introduction

Nutritional deficiencies (NDs), 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, behavior, and overall health [3; 4; 5; 6]. NDs often play a causative role in the development of various diseases and can contribute to their undesirable progression [7; 8; 9]. It is worth noting that NDs can predispose individuals to infectious and oncological complications, such as COVID-19 [10; 11].

Given the significant occurrence and outcomes associated with NDs, Various governments and organizations 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 NDs [12; 13; 14]. However, the world is moving away from the goal of ending hunger. A comprehensive exploration of global epidemiologic patterns for NDs 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, DALYs, prevalence, and mortality) of NDs 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 categorized with different variables (sex, age, cause, and 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 publicly available, the present study did not require informed patient

consent. Data stratified by age, gender, year, and geographic area, include the number and rate (per 100000 population) of diverse factors (new cases, DALYs, illnesses, and deaths) [16]. Data collection was achieved through the Global Health Data Exchange (GHDx) query tool, which utilizes 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 (YLDs) and Years of Life Lost (YLLs), we can obtain the total number of DALYs 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), NDs were categorized into 5 types: Dietary iron 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 nutritional deficiencies (ICD10 codes: D51~D53.9, E51~E61.9, E63~E64, and E64.2~E64.9) [20; 21]. This classification system is widely recognized and used in the field of healthcare to classify and code diseases and health conditions. By utilizing ICD-10 codes, we aimed to ensure consistency and comparability in our study. The five specific etiologies (Dietary iron deficiency, Iodine deficiency, Protein-energy malnutrition, Vitamin A deficiency, and Other nutritional deficiencies) 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 minimize 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 5 parts, including low, low-middle, middle, high-middle, and high SDI, based on a socio-demographic index (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 (AAPCs) were used to explore global trends in NDs. 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 APCs 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. AAPCs can signify the percentage change (increase, decrease, or no change) from year to year. AAPCs 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 analyzing 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, gender, 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. $p < 0.05$ (two-sided) were deemed statistically significant [29].

Results

Global trends

Globally, the NDs incidence generally decreased between 1990 and 2019 (AAPC = -0.21 [95% CI -0.31 to -0.11), with the most significant decreasing period occurring between 1990 and 1999 (AAPC = -0.36 [-0.39 to -0.33], Table 1). Incidence counts of NDs increased between 1990 and 2019, however, the changes in incident rates were positive. Altogether, the incident rate of NDs decreased from 2226.2 (1850.4-2689.6) per 100000 population in 1990 to 2096.3 (1766.1-2472.4) per 100000 population in 2019, a decrease of 5.8% (Table 2). The joinpoint regression determined a considerable change in the incidence of NDs in 2005, 2010, 2014, and 2017 (Fig. 1). Meanwhile, DALYs (AAPC = -3.21 [-3.45 to -2.96]), prevalence (AAPC = -0.53 [-0.55 to -0.51]), and mortality rate (AAPC = -4.97 [-5.75 to -4.19]) of NDs have decreased notably. The DALYs, prevalence, and mortality rate decreased by 60.8%, 14.2%, and 76.8% between 1990 and 2019, respectively (Table 2, Table S1).

Global trends by sex

Although female (AAPC = -0.36, $p < 0.001$) incidence rates decreased between 1990 and 2019, a similar pattern has not been observed in male (AAPC = -0.07, $p = 0.137$; 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 genders, with the trough located in 2015. Notably, the increasing trend in NDs among males and females has become more pronounced since 2015 (Fig. 2).

Both the number and rate of DALYs dropped dramatically, with lower declines for males than for females (AAPC -3.55 [95% CI -3.15 to -2.71] vs. -2.93 95% CI [-3.15 to -2.71], Table 3). Similarly, the prevalence rate and mortality of NDs fell markedly in both genders, more so for males than for females (Table S3, Figure S1).

Global trends by age group

From 1990 to 2019, the incident rate in children and younger adolescents aged 0-14 years was remarkedly 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 NDs in children and adolescents (48554506 in 1990 to 52330896 in 2019), young adults (28453520 in 1990 to 56174614 in 2019), older adults (8443472 in 1990 to 24712546 in 2019), and older people (1320007 in 1990 to 4488917 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 DALYs, prevalence, and mortality in all age groups significantly dropped (Table 3, Table S2, Fig. S1).

Global trends by causes

As presented in Table 2 and Fig.2, Vitamin A deficiency is the most predominant subtype of NDs, with a decreasing trend in its incident number and incident rate from 1990 and 2019. Protein-energy malnutrition was another undesirable type of NDs, with a serious global burden for DALYs (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 Table S1 and Table S2.

Global trends by SDI

The incidence rates of NDs 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 NDs in middle, middle-high, and high SDI areas was 0.81, 1.44, and 0.63 respectively, while the AAPC for NDs in low and low-middle SDI areas was -0.88 and -0.68 (Table 3). Nevertheless, in 2019, the incident rate of NDs per 100000 population remains lower in middle and above SDI areas than in low or low-middle SDI areas. Moreover, the incident number of NDs in 2019 has increased in all SDI regions compared to 1990 (Table 2).

DALY rates showed a decreasing direction in all SDI areas (Table 2), and the AAPCs of incidence rate in all SDI areas were also decreasing (all AAPC < 0, all $p < 0.001$, Table 3). Notably, the high SDI area was the only area where the incident number of NDs 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 (Table S1).

Regional trends

The incident number of NDs 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 to 78770018]) and incident rate (3677.2 [95% CI 3067.9 to 4363.5] per 100,000 population) of NDs in 2019. However, NDs have increased the most in Oceania (83.2%), from 146029 in 1990 to 267590 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 DALYs 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 DALYs rate declined in the majority of these regions

from 1990 to 2019 (AAPC < 0, p < 0.001, 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 Table S1 and Table S2.

National trends

As shown in Fig. 3, the highest incident rates of NDs in 2019 were in Maldives (4802.7 [95% CI 3936.3 to 5785.3] per 100,000 population), Sri Lanka (4679.5 [95% CI 3851.1 to 5635.8] per 100,000 population), and India (4030.4 [95% CI 3323.1 to 4817] per 100,000 population). Meanwhile, the most predominant increase in NDs' 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 (Figure S2).

Evidently, the country with the greatest DALY rate for NDs in 2019 was Mali (6770.1 [95% CI 4916 to 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 United States of America (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 (Fig. S2). Furthermore, the additional information for the prevalence and mortality of NDs between 1990 and 2019 was presented in Fig S3-S5.

Trends between NDs and SDI

Globally, incidence, DALYs, prevalence, and mortality presented a striking negative association with SDI (R < 0, p < 0.001; Fig. 5, Fig. S6). The incidence of NDs 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 NDs (Fig. 5). The DALYs 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 SDI. Furthermore, as the low SDI regions, Sub-Saharan Africa and South Asia presented the highest mortality rates for NDs (Fig. S6).

Discussion

To date, this is the first research to discuss changes in the incidence, DALYs, prevalence, and mortality of NDs from 1990 to 2019 at global, regional, and national levels. The incident rates of NDs showed a falling-rising trend, while the DALYs rates have declined in the past 30 years. And the enormous incidence number of NDs shows that it remains an inescapable global threat. Meanwhile, the incident rates of NDs 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 etiology, 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, DALYs, prevalence, and mortality rates are largely dropping for all genders, ages, causes, and regions (AAPC < 0), albeit to varying degrees.

The number of people suffering from NDs is growing in parallel with the global population, and all countries and territories continue to struggle with any form of NDs [30]. Incident numbers of NDs increased from 119100916 in 1990 to 162197527 in 2019, an increase of 36.2%. The risk of NDs is greatest in males, infants, children, and adolescents. The majority of child deaths are directly or indirectly attributable to NDs worldwide [31]. For children and younger adolescents aged 0-14 years, the incidence, DALY, prevalence, and mortality rates of NDs in 2019 were all decreasing compared to 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 genders. 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 nutritional deficiencies [32].

Also, national and regional differences were observed in the popularization of NDs.

Nationally, developing countries are the areas most affected by NDs, and the morbidity of NDs in India was markedly higher than in other countries. Severe nutritional deficiencies lead to a weakened immune function [33; 34], and this phenomenon may be responsible for the prevalence of infectious diseases in India. We found DALYs and deaths associated with NDs 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; 36; 37]. Regionally, we observed that the incidence of NDs is highest in Asia, but fastest growing in Africa. South Asia remains the 'hardest hit' by NDs, with about 3677 per 100000 population, almost three times as many as in sub-Saharan Africa. Meanwhile, it is notable that NDs in Asia and Africa indicate a significant year-on-year decrease. Poverty exacerbates the development of NDs, and people living in poverty (low or low-middle SDI areas) are more likely to be affected by NDs. Additionally, NDs 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 popularization 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 NDs, this goal by 2030 will be difficult to achieve [40; 41]. It is essential to discover temporal trends in the global burden of NDs, thus indicating the effectiveness of existing nutrition promotion strategies and strengthening guidance to global organizations to control NDs. 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 NDs and bring about significant savings.

In response to the burden of NDs, various policies and actions have been implemented in the area of nutritional health care. These efforts aim to improve the availability, accessibility, and

affordability of nutritious food, and to strengthen nutrition education and counseling. Interventions such as fortification of staple foods, promotion of breastfeeding and implementation of school feeding programs have also been initiated to address specific NDs [44]. It is also recognized 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, gender, and specific NDs.

Inevitably, there are some limitations to our study. Firstly, this study is restricted by collected variables and missing data in GBD, particularly the etiological category. Data on poorer areas may be underestimated due to the lack of efficient statistical instruments. Secondly, additional factors may influence the development of NDs, 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 standardized data collection protocols and training programs. Additionally, research should explore emerging trends in ND etiology 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 NDs 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 NDs.

Author contribution

All authors contributed to the study's conception and design. XQ performed data collection and analysis. XQ and YJ wrote the manuscript. KW, KX, and CY polished and revised the manuscript. All authors commented on previous versions of the manuscript and read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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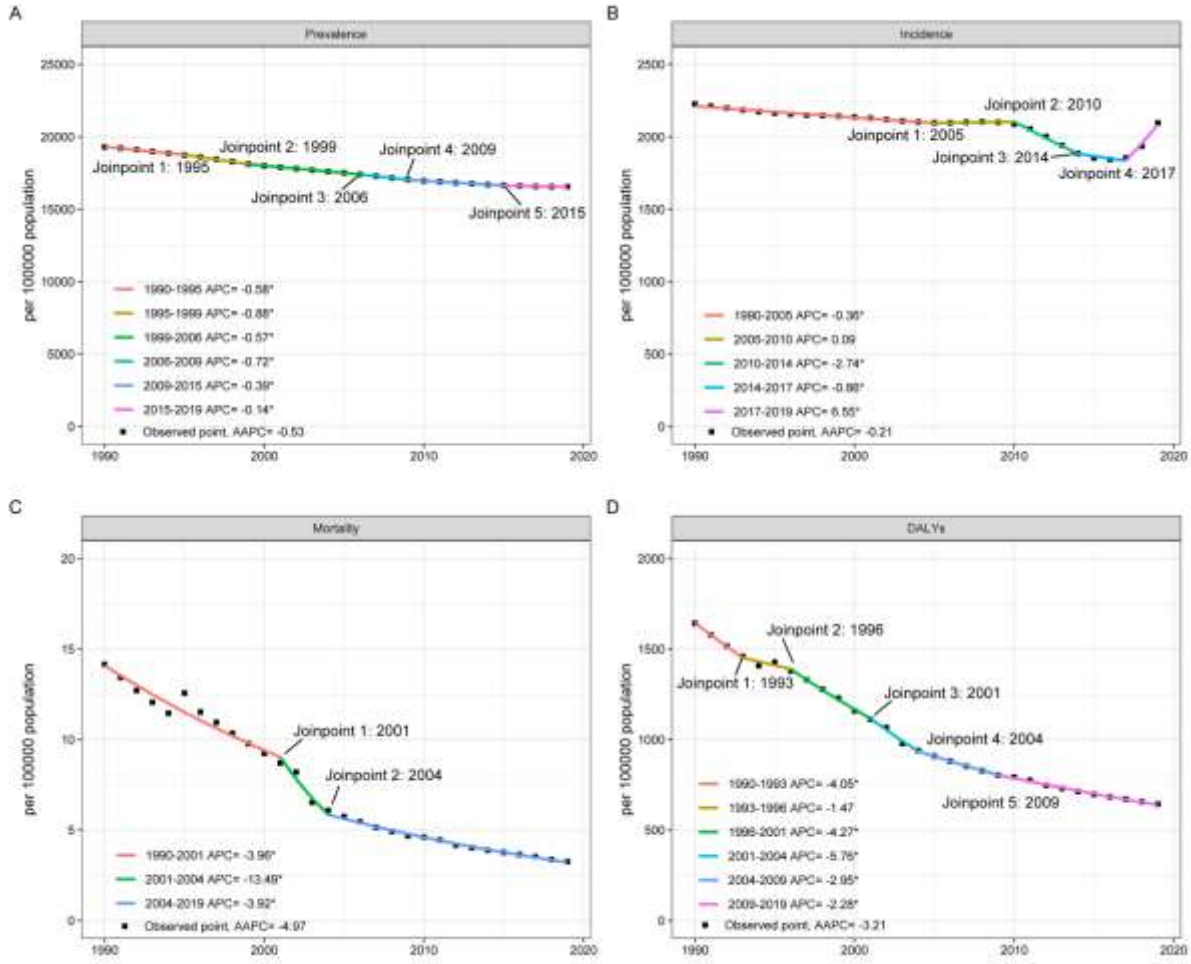

Fig. 1. Joinpoint regression analysis of global trend for NDs from 1990 to 2019. A Prevalence, B Incidence, C Mortality, D DALYs.

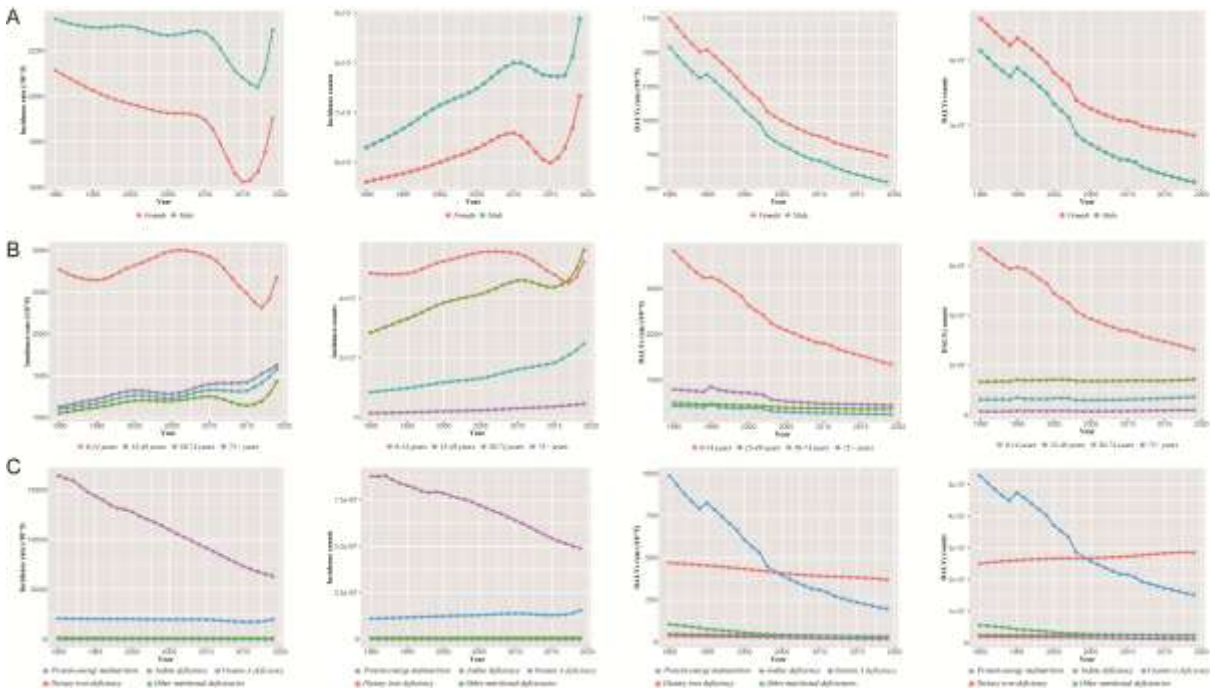

Fig. 2. Incidence and DALYs of NDs in subgroups from 1990 to 2019. A Sex, B Age, C Causes.

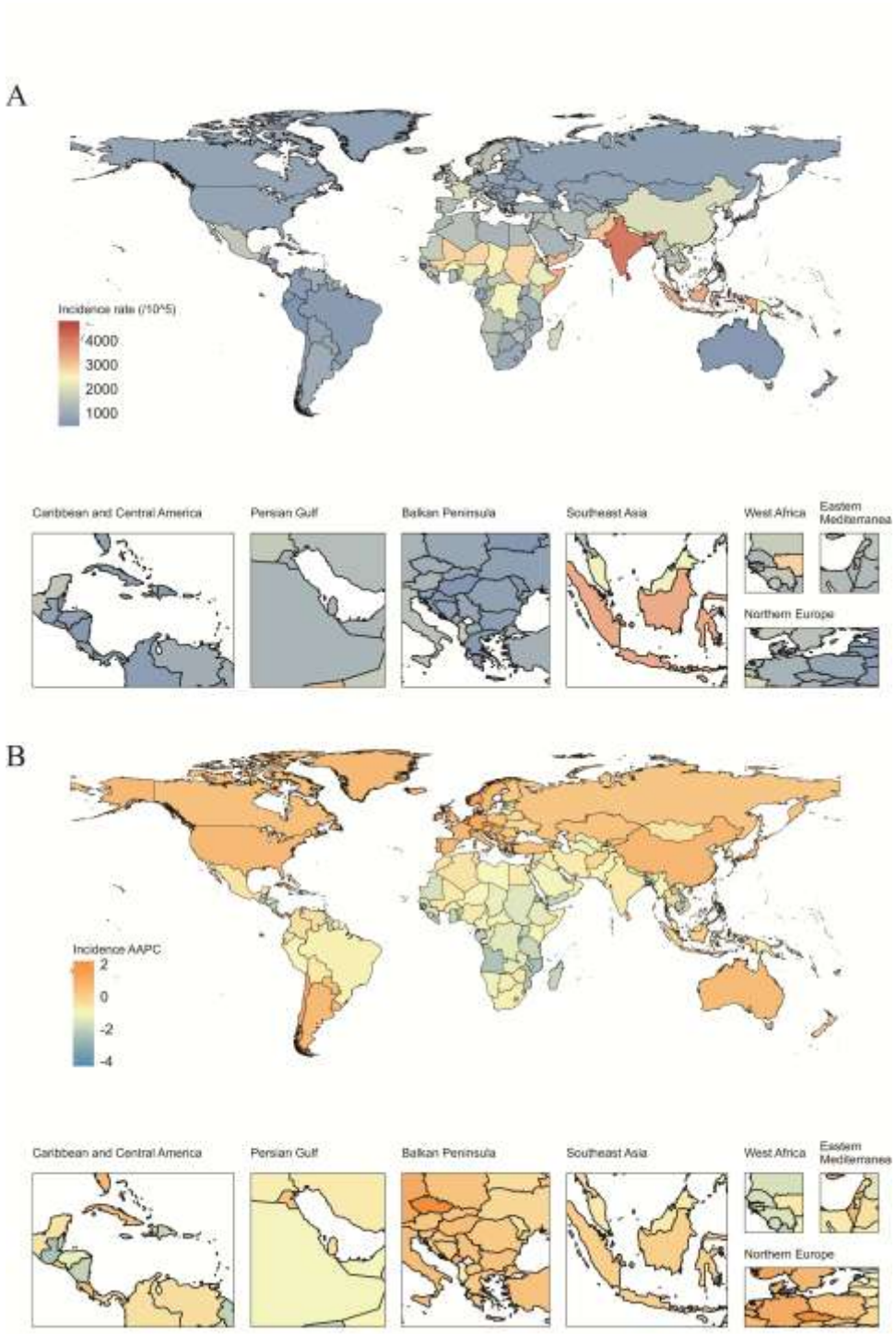

Fig. 3. Geographical distribution of NDs incidence in 204 countries and territories. A Incidence rate of NDs in 2019, B AAPC in incidence rate of NDs between 1990 and 2019.

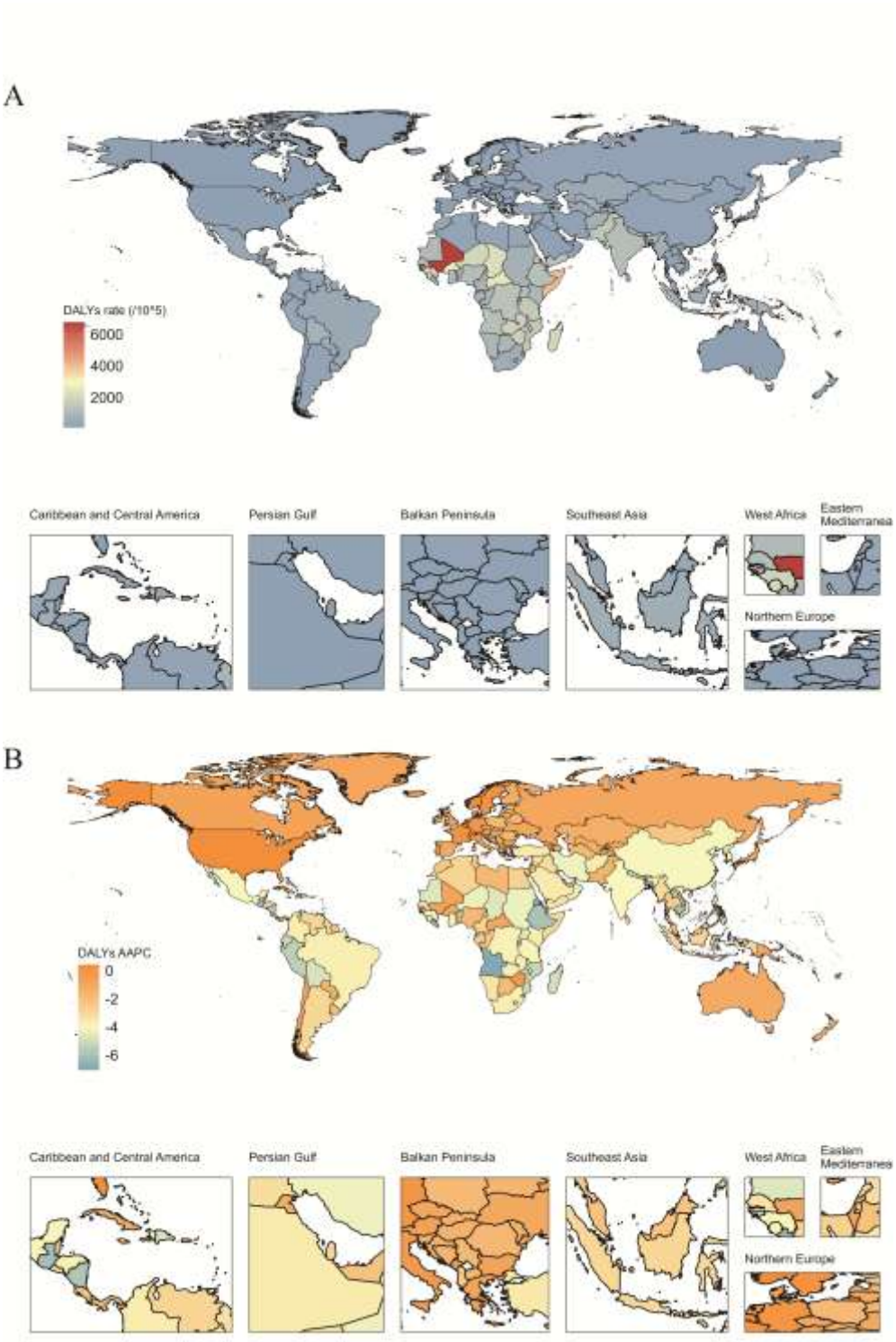

Fig. 4. Geographical distribution of NDs DALYs in 204 countries and territories. A DALYs rate of NDs in 2019, B AAPC in DALYs rate of NDs between 1990 and 2019.

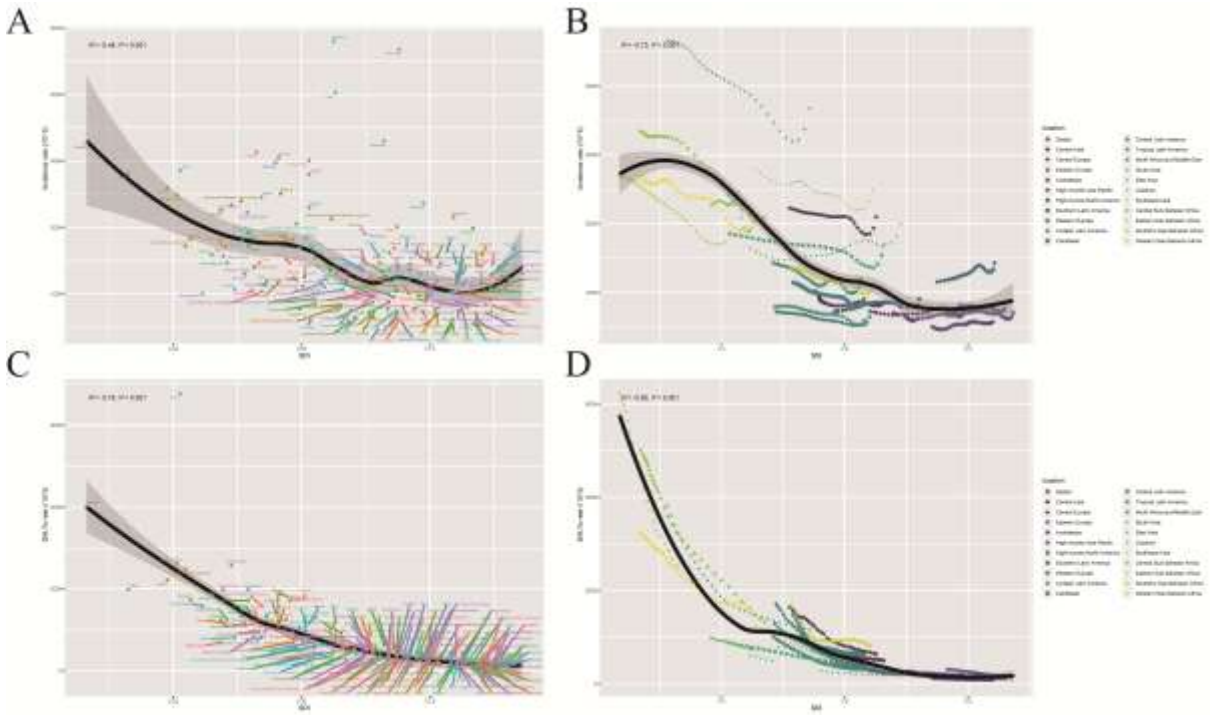

Fig. 5. Global, 21 regions, and 204 countries and territories burden of NDs by SDI, from 1990 to 2019. A Incidence per 100,000 population in global and 204 countries and territories, B Incidence per 100,000 population in global and 21 regions, C DALYs per 100,000 population in global and 204 countries and territories, D DALYs per 100,000 population in global and 21 regions. For each region, points from left to right depict estimates from each year from 1990 to 2019.

Table 1. Global AAPCs in prevalence, incidence, mortality, and DALYs of NDs.

Period	Incidence		Prevalence		Mortality		DALYs	
	AAPC (95%CI)	p-value	AAPC (95%CI)	p-value	AAPC (95%CI)	p-value	AAPC (95%CI)	p-value
1990-99	-0.36 (-0.39 to -0.33)	<0.001	-0.71 (-0.74 to -0.68)	<0.001	-3.96 (-4.62 to -3.3)	<0.001	-3.27 (-3.81 to -2.73)	<0.001
2000-09	-0.16 (-0.26 to -0.06)	<0.001	-0.62 (-0.66 to -0.57)	<0.001	-7.23 (-9.53 to -4.87)	<0.001	-4.04 (-4.57 to -3.51)	<0.001
2010-19	-0.11 (-0.4 to -0.18)	0.456	-0.28 (-0.31 to -0.26)	<0.001	-3.92 (-4.11 to -3.73)	<0.001	-2.28 (-2.42 to -2.13)	<0.001
1990-2019	-0.21 (-0.31 to -0.11)	<0.001	-0.53 (-0.55 to -0.51)	<0.001	-4.97 (-5.75 to -4.19)	<0.001	-3.21 (-3.45 to -2.96)	<0.001

AAPC: Average annual percentage change; DALYs: Disability-adjusted life-years.

Table 2. Incidence and DALYs of NDs at global and regional levels.

	Incidence						DALYs					
	No., 1990	No., 2019	No. change (%)	Rate 1990 (/10^5)	Rate 2019 (/10^5)	Rate change (%)	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	87847408 (69856803-111925183)	49775124 (36889950-65839422)	-43.3	1642.1 (1305.8-2092.1)	643.3 (476.8-850.9)	-60.8
Sex												
Female	56092090 (46329895-68634960)	73336482 (62109683-86022374)	30.7	2111.8 (1744.3-2584.1)	1901.6 (1610.5-2230.6)	-10	46388584 (33318803-62520514)	28456555 (21132186-37721021)	-38.7	1746.5 (1254.4-2353.8)	737.9 (548-978.1)	-57.7
Male	63008825 (52536241-76085024)	88861046 (74392565-105463458)	41	2339.1 (1950.3-2824.5)	2289.7 (1916.9-2717.4)	-2.1	41458824 (33665854-50453511)	21318569 (16030317-27817401)	-48.6	1539.1 (1249.8-1873)	549.3 (413-716.8)	-64.3
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	67004080 (52751021-86643264)	26339578 (20235568-33595123)	-60.7	3820.1 (3007.5-4939.8)	1344 (1032.6-1714.2)	-184.2
15-49	28453520 (22976506-35746479)	56174614 (45329045-70552538)	97.4	1049.1 (847.2-1318)	1427.5 (1151.9-1792.9)	36.1	13310246 (9566292-18078244)	14322502 (9731752-20090519)	7.6	490.8 (352.7-666.6)	364 (247.3-510.5)	-25.8
50-74	8443472 (6703400-10336043)	24712546 (19446280-30511883)	192.7	1101.3 (874.4-1348.2)	1578 (1241.8-1948.4)	43.3	6166867 (4672969-7984295)	7223933 (5248758-9675620)	17.1	425.7 (322.5-551.1)	245.3 (178.2-328.5)	-42.4
75+	1320007 (1014237-1659250)	4488917 (3412420-5724572)	240.1	1127.9 (866.6-1417.8)	1623 (1233.8-2069.7)	43.9	1366215 (1107323-1644849)	1889111 (1562613-2326713)	38.3	790.8 (641-952.1)	443.3 (366.7-546)	-43.9

Cause												
Dietary iron deficiency	0 (0-0)	0 (0-0)	NA	0 (0-0)	0 (0-0)	NA	25069790 (16835783-36058206)	28534680 (19127591-41139284)	13.8	468.6 (314.7-674)	368.8 (247.2-531.7)	-21.3
Iodine deficiency	7711749 (6265218-9349772)	8111508 (6500143-9966057)	5.2	144.1 (117.1-174.8)	104.8 (84-128.8)	-27.3	2499955 (1534318-4033663)	2438599 (1372657-4238613)	-2.5	46.7 (28.7-75.4)	31.5 (17.7-54.8)	-32.5
Other nutritional deficiencies	0 (0-0)	0 (0-0)	NA	0 (0-0)	0 (0-0)	NA	5566372 (3545372-7693399)	2367814 (1879522-2950809)	-57.5	104 (66.3-143.8)	30.6 (24.3-38.1)	-70.6
Protein-energy malnutrition	111389167 (91268425-136380189)	154086019 (128445223-183279047)	38.3	2082.1 (1706-2549.2)	1991.4 (1660-2368.7)	-4.4	52743908 (40250363-70481552)	15256524 (12565114-18327803)	-71.1	985.9 (752.4-1317.4)	197.2 (162.4-236.9)	-80
Vitamin A deficiency	877376295 (840347028-914976465)	489662709 (469006374-512234291)	-44.2	16400 (15707.9-17102.9)	6328.5 (6061.5-6620.2)	-61.4	1967383 (1362752-2795113)	1177507 (805056-1636582)	-40.1	36.8 (25.5-52.2)	15.2 (10.4-21.2)	-58.7
SDI												
High-middle	7276517 (5964657-8821153)	10845728 (8773025-13098262)	49.1	885.2 (725.6-1073.1)	1070.2 (865.7-1292.5)	20.9	5641095 (4216113-7503141)	1456034 (1049926-1973130)	-74.2	188 (129.9-262)	143.7 (103.6-194.7)	-23.6
High	11770875 (9975302-14168351)	22294079 (18224647-27126083)	89.4	1023.2 (867.1-1231.6)	1558.6 (1274.1-1896.4)	52.3	1545153 (1067509-2153516)	3777225 (2628068-5243542)	144.5	490.3 (366.5-652.2)	264.1 (183.7-366.6)	-46.1
Low-middle	13769154 (12900074-14849368)	22852411 (20865622-25426217)	66	2607.1 (2442.5-2811.6)	2024.7 (1848.7-2252.7)	-22.3	38381607 (28444221-50860085)	18299217 (14184880-23321623)	-52.3	4949.4 (3981.4-6377.7)	1621.3 (1256.8-2066.3)	-67.2
Low	29595898 (27168207-3268531	38142885 (33348332-4454107	28.9	2619.9 (2405-2893.4)	2162.3 (1890.5-2525	-17.5	26139782 (21027530-336831	16197717 (11889740-217657	-38	3397.7 (2518-4502.3	918.2 (674-1233.9)	-73

	6)	6)			)		00)	79)		)		
Middle	24817909	43941882	77.1	1445.6	1833.5	26.8	16099695	10018418	-37.8	937.8	418	-55.4
	(21616005-2901871	(37056080-5270921		(1259.1-1690.3	(1546.2-2199		(12945701-202065	(7136818-1354761		(754.1-1177)	(297.8-565.3)	
	1)	1)		)	.4)		40)	9)				
Region												
Andean	275990	377625	36.8	722.9	593.8	-17.9	653310	240935	-63.1	1711.3	378.9	-77.9
Latin	(241350-313904)	(332461-431579)		(632.2-822.2)	(522.8-678.6)		(546236-780019)	(179774-317266)		(1430.8-2043	(282.7-498.9)	
America										.2)		
Australasi	101595	166503	63.9	501	572.9	14.4	24867	25809	3.8	122.6	88.8	-27.6
a	(85123-122118)	(138737-199068)		(419.8-602.2)	(477.4-684.9)		(16461-37475)	(17292-36906)		(81.2-184.8)	(59.5-127)	
Caribbea	403462	422723	4.8	1143.8	896.2	-21.6	523710	292017	-44.2	1484.7	619.1	-58.3
n	(333913-485097)	(356807-499164)		(946.6-1375.2)	(756.5-1058.		(412459-669429)	(220700-380301)		(1169.3-1897	(467.9-806.3)	
					3)					.8)		
Central	703552	802198	14	1015.7	857.7	-15.6	502901	466713	-7.2	726	499	-31.3
Asia	(595028-843428)	(674819-960613)		(859-1217.7)	(721.5-1027.		(353263-697873)	(310559-663201)		(510-1007.5)	(332-709.1)	
					1)							
Central	894782	944062	5.5	727.7	826.5	13.6	335495	193281	-42.4	272.8	169.2	-38
Europe	(702387-1118547)	(754100-1170503)		(571.2-909.6)	(660.2-1024.		(222099-481486)	(129245-277703)		(180.6-391.6)	(113.2-243.1)	
					7)							
Central	2339702	2975636	27.2	1425.6	1190.2	-16.5	1645199	768753	-53.3	1002.4	307.5	-69.3
Latin	(1982059-2755385)	(2483002-3527054)		(1207.7-1678.9	(993.1-1410.		(1449248-1886605)	(612602-963123)		(883-1149.5)	(245-385.2)	
America				)	7)							
Central	1855710	2746499	48	3342.4	2087.9	-37.5	2783190	1739853	-37.5	5013	1322.6	-73.6
Sub-Sahara	(1529910-2261595)	(2373993-3206242)		(2755.6-4073.5	(1804.7-2437		(2030245-3858035)	(1284272-2316849		(3656.8-6948	(976.3-1761.	
n Africa				)	.4)			)		.9)	3)	
East Asia	20146456	29341667	45.6	1644.4	1993	21.2	7297459	2736622	-62.5	595.6	185.9	-68.8
	(15382935-2636989	(23187621-3634421		(1255.6-2152.4	(1575-2468.7		(5812959-9226732)	(1906356-3833472		(474.5-753.1)	(129.5-260.4)	
	2)	5)		)	)			)				

Eastern Europe	1598906 (1311442-1934824)	1539084 (1223373-1896299)	-3.7	705.9 (579-854.2)	733 (582.6-903.1)	3.8	551271 (383060-776640)	379716 (258871-546433)	-31.1	243.4 (169.1-342.9)	180.8 (123.3-260.2)	-25.7
Eastern Sub-Saharan Africa	5113069 (4193513-6339469)	7142597 (6072122-8380019)	39.7	2688.7 (2205.2-3333.6)	1734.6 (1474.6-2035.1)	-35.5	11832134 (9543220-15180255)	6298676 (4988236-7823056)	-46.8	6222 (5018.4-7982.6)	1529.6 (1211.4-1899.8)	-75.4
High-income Asia Pacific	1148722 (958522-1382369)	1323670 (1075415-1613426)	15.2	662 (552.4-796.7)	706.7 (574.2-861.5)	6.8	537633 (360263-786927)	317743 (215860-455273)	-40.9	309.9 (207.6-453.5)	169.7 (115.3-243.1)	-45.2
High-income North America	1954927 (1541789-2443335)	3072006 (2418972-3776253)	57.1	695.9 (548.8-869.7)	842.7 (663.5-1035.8)	21.1	316133 (222888-428586)	443235 (322522-601267)	40.2	112.5 (79.3-152.6)	121.6 (88.5-164.9)	8.1
North Africa and Middle East	6392740 (5295931-7803246)	9359303 (8040842-10846679)	46.4	1852.8 (1534.9-2261.6)	1537.6 (1321-1781.9)	-17	3022827 (2200940-4448876)	2136443 (1525524-2983497)	-29.3	876.1 (637.9-1289.4)	351 (250.6-490.1)	-59.9
Oceania	146029 (119239-182720)	267590 (214799-331684)	83.2	2257.1 (1843-2824.2)	2015.5 (1617.9-2498.3)	-10.7	63875 (47608-83655)	96887 (68688-133223)	51.7	987.3 (735.8-1293)	729.8 (517.4-1003.5)	-26.1
South Asia	51014128 (43090664-61007431)	66381377 (55381877-78770018)	30.1	4647.7 (3925.8-5558.1)	3677.2 (3067.9-4363.5)	-20.9	42043737 (30639129-55964842)	20946037 (14876928-28637410)	-50.2	3830.4 (2791.4-5098.7)	1160.3 (824.1-1586.4)	-69.7
Southeast Asia	13068191 (10878824-15755895)	16813154 (14213233-19563548)	28.7	2799.6 (2330.6-3375.4)	2495.3 (2109.5-2903.5)	-10.9	5727002 (4466977-7426074)	3162732 (2361354-4261032)	-44.8	1226.9 (957-1590.9)	469.4 (350.5-632.4)	-61.7
Southern Latin America	358520 (303948-422954)	605049 (501197-727121)	68.8	723.7 (613.5-853.7)	906.4 (750.8-1089.3)	25.2	208293 (163454-269448)	132057 (97091-180802)	-36.6	420.4 (329.9-543.9)	197.8 (145.4-270.9)	-52.9
Southern Sub-Sahara	721116 (607342-876342)	842428 (716190-992425)	16.8	1373.7 (1157-1669.4)	1072.1 (911.5-1263)	-22	887613 (722902-1077314)	632595 (498189-787208)	-28.7	1690.9 (1377.1-2052	805.1 (634-1001.9)	-52.4

n Africa										.3)		
Tropical Latin America	1210380 (986379-1483967)	1439938 (1206775-1712146)	19	791.7 (645.2-970.7)	644 (539.7-765.7)	-18.7	1967557 (1621313-2370941)	971908 (711188-1356678)	-50.6	1287 (1060.5-1550 .8)	434.7 (318.1-606.8)	-66.2
Western Europe	4439749 (3657274-5447233)	6221989 (5080799-7541776)	40.1	1154.4 (950.9-1416.4)	1426.1 (1164.5-1728 .5)	23.5	650451 (445993-890965)	667370 (470188-896059)	2.6	169.1 (116-231.7)	153 (107.8-205.4)	-9.5
Western Sub-Sahara n Africa	5213190 (4226168-6529639)	9412428 (8157715-11017349)	80.6	2707 (2194.5-3390.6)	2062.7 (1787.7-2414 .4)	-23.8	6272748 (5015144-7809590)	7125742 (5449404-9185621)	13.6	3257.2 (2604.2-4055 .2)	1561.6 (1194.2-2013)	-52.1

DALYs: Disability-adjusted life-years; SDI: Socio-demographic index.

Table 3. Subgroups AAPCs in incidence and DALYs of NDs.

	Incidence		DALYs	
	AAPC (95% CI)	p-value	AAPC (95% CI)	p-value
Global	-0.21 (-0.31 to -0.11)	<0.001	-3.21 (-3.45 to -2.96)	<0.001
Sex				
Female	-0.36 (-0.44 to -0.28)	<0.001	-2.93 (-3.15 to -2.71)	<0.001
Male	-0.07 (-0.17 to 0.02)	0.137	-3.55 (-3.86 to -3.24)	<0.001
Age, years				
0-14	-0.14 (-0.24 to -0.04)	0.006	-3.53 (-3.75 to -3.31)	<0.001
15-49	1.05 (0.97 to 1.13)	<0.001	-1.03 (-1.27 to -0.79)	<0.001
50-74	1.23 (1.1 to 1.36)	<0.001	-1.95 (-2.71 to -1.19)	<0.001
75+	1.26 (1.21 to 1.32)	<0.001	-2 (-2.77 to -1.21)	<0.001
Cause				
Protein-energy malnutrition	-0.15 (-0.34 to 0.03)	0.108	-5.36 (-5.69 to -5.03)	<0.001
Iodine deficiency	-1.1 (-1.15 to -1.05)	<0.001	-1.35 (-1.43 to -1.27)	<0.001
Vitamin A deficiency	-3.24 (-3.4 to -3.08)	<0.001	-3 (-3.03 to -2.96)	<0.001
Dietary iron deficiency	NA	NA	-0.82 (-0.84 to -0.81)	<0.001
Other nutritional deficiencies	NA	NA	-4.22 (-4.55 to -3.89)	<0.001
SDI				
High	0.63 (0.6 to 0.66)	<0.001	-0.93 (-1.08 to -0.79)	<0.001
High-middle	1.44 (1.2 to 1.69)	<0.001	-2.12 (-2.22 to -2.02)	<0.001
Low	-0.88 (-0.97 to -0.78)	<0.001	-3.8 (-3.94 to -3.65)	<0.001
Low-middle	-0.68 (-0.89 to -0.46)	<0.001	-4.46 (-5.01 to -3.9)	<0.001
Middle	0.81 (0.53 to 1.1)	<0.001	-2.76 (-2.86 to -2.67)	<0.001
Region				
Andean Latin America	-4.5 (-4.71 to -4.29)	<0.001	-0.71 (-0.79 to -0.64)	<0.001
Australasia	1.22 (0.98 to 1.46)	<0.001	0.49 (0.3 to 0.68)	<0.001
Caribbean	-4.11 (-4.33 to -3.9)	<0.001	-0.87 (-1 to -0.75)	<0.001

Central Asia	-4.65 (-5.02 to -4.27)	<0.001	-0.62 (-0.83 to -0.42)	<0.001
Central Europe	2.88 (2.49 to 3.26)	<0.001	0.43 (0.33 to 0.52)	<0.001
Central Latin America	-3.59 (-3.88 to -3.31)	<0.001	-0.65 (-0.76 to -0.53)	<0.001
Central Sub-Saharan Africa	-6.03 (-6.14 to -5.93)	<0.001	-1.58 (-1.82 to -1.35)	<0.001
East Asia	-3.77 (-10.18 to 3.1)	0.275	0.64 (0.49 to 0.79)	<0.001
Eastern Europe	-0.76 (-1.63 to 0.13)	0.093	0.11 (-0.02 to 0.24)	0.111
Eastern Sub-Saharan Africa	-5.72 (-6.22 to -5.22)	<0.001	-1.51 (-1.57 to -1.45)	<0.001
High-income Asia Pacific	2.2 (1.77 to 2.63)	<0.001	0.2 (0.14 to 0.26)	<0.001
High-income North America	1.7 (1.37 to 2.04)	<0.001	0.62 (0.52 to 0.71)	<0.001
North Africa and Middle East	-5.38 (-5.54 to -5.22)	<0.001	-0.67 (-0.72 to -0.62)	<0.001
Oceania	-2.39 (-2.77 to -2)	<0.001	-0.52 (-0.74 to -0.3)	<0.001
South Asia	-8.41 (-8.64 to -8.19)	<0.001	-0.83 (-1.01 to -0.64)	<0.001
Southeast Asia	-3.01 (-3.08 to -2.95)	<0.001	-0.4 (-0.72 to -0.08)	<0.001
Southern Latin America	-0.19 (-0.61 to 0.23)	0.38	0.74 (0.64 to 0.84)	0.015
Southern Sub-Saharan Africa	-2.82 (-3.19 to -2.45)	<0.001	-0.87 (-1.04 to -0.7)	<0.001
Tropical Latin America	-3.52 (-3.73 to -3.31)	<0.001	-0.75 (-0.85 to -0.66)	<0.001
Western Europe	2.11 (1.89 to 2.33)	<0.001	0.71 (0.66 to 0.75)	<0.001
Western Sub-Saharan Africa	-4.12 (-4.44 to -3.79)	<0.001	-0.95 (-1.11 to -0.78)	<0.001

DALYs: Disability-adjusted life-years; AAPC: Average annual percentage change; SDI: Socio-demographic index.