Association between inequalities in human resources for health and all cause and cause specific mortality in 172 countries and territories, 1990-2019: observational study

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ABSTRACT

OBJECTIVE
To explore inequalities in human resources for health (HRH) in relation to all cause and cause specific mortality globally in 1990-2019.

DESIGN
Observational study.

SETTING
172 countries and territories.

DATA SOURCES
Databases of the Global Burden of Disease Study 2019, United Nations Statistics, and Our World in Data.

MAIN OUTCOME MEASURES
The main outcome was age standardized all cause mortality per 100 000 population in relation to HRH density per 10 000 population, and secondary outcome was age standardized cause specific mortality. The Lorenz curve and the concentration index (CCI) were used to assess trends and inequalities in HRH.

RESULTS
Globally, the total HRH density per 10 000 population increased, from 56.0 in 1990 to 142.5 in 2019, whereas age standardized all cause mortality per 100 000 population decreased, from 995.5 in 1990 to 743.8 in 2019. The Lorenz curve lay below the equality line and CCI was 0.43 ($P<0.05$), indicating that the health workforce was more concentrated among countries and territories ranked high on the human development index. The CCI for HRH was stable, at about 0.42-0.43 between 1990 and 2001 and continued to decline (narrowed inequality), from 0.43 in 2001 to 0.38 in 2019 ($P<0.001$). In the multivariable generalized estimating equation model, a negative association was found between total HRH level and all cause mortality, with the highest levels of HRH as reference (low: incidence risk ratio 1.15, 95% confidence interval 1.00 to 1.32; middle: 1.14, 1.01 to 1.29; high: 1.18, 1.08 to 1.28). A negative association between total HRH density and mortality rate was more pronounced for some types of cause specific mortality, including neglected tropical diseases and malaria, enteric infections, maternal and neonatal disorders, and diabetes and kidney diseases. The risk of death was more likely to be higher in people from countries and territories with a lower density of doctors, dentistry staff, pharmaceutical staff, aides and emergency medical workers, optometrists, psychologists, personal care workers, physiotherapists, and radiographers.

CONCLUSIONS
Inequalities in HRH have been decreasing over the past 30 years globally but persist. All cause mortality and most types of cause specific mortality were relatively higher in countries and territories with a limited health workforce, especially for several specific HRH types among priority diseases. The findings highlight the importance of strengthening political commitment to develop equity oriented health workforce policies, expanding health financing, and implementing targeted measures to reduce deaths related to inadequate HRH to achieve universal health coverage by 2030.

WHAT IS ALREADY KNOWN ON THIS TOPIC
Human resources for health (HRH), a range of occupations to promote or improve health, are of importance to achieve universal health coverage by 2030

Although several studies have analyzed the relation between HRH density and mortality rate, most focused on maternal mortality ratio and mortality rates in under-5s, infants, and neonates

Studies focusing on inequalities in total and specific HRH types and relations with cause specific mortality from a global perspective across three decades are scare

WHAT THIS STUDY ADDS
Inequalities in HRH have been decreasing globally over the past 30 years but persist

The negative association between total HRH density and mortality rate was statistically significant and more pronounced for some types of cause specific mortality

Countries and territories should refocus on the human resource pool of priority HRH cadres on the basis of leading cause specific mortality

Introduction
Human resources for health (HRH), a range of occupations designed to promote or improve human health, are of vital importance in the process of achieving universal health coverage by 2030.[1-3] In September 2015, the United Nations adopted a new development agenda, with 17 sustainable development goals replacing the millennium development goals, and sustainable development goal 3 focusing on a broad range of health goals.[4-6] One of the specific targets of sustainable development goal 3 is to substantially increase health financing and the recruitment, development, training, and retention of the health workforce in developing countries.[5] In July 2020, the World Health Organization, through its global strategy for HRH, further reaffirmed the vision

to accelerate progress towards achieving universal health coverage and the sustainable development goals by ensuring equitable access to health workers in strengthened health systems.[7] Global public health emergencies such as the covid-19 pandemic also present major challenges to the availability, equity, and future planning of HRH globally.[8]

HRH is one of the essential safeguards for health.[9] Practically, a shortage in HRH was the most conspicuous constraint on the lack of success of many countries to achieve the three health related millennium development goal targets—reducing child mortality, improving maternal health, and combat HIV/AIDS and other diseases.[10-14] Achieving universal health coverage depends not only on the availability of a sufficient number of qualified and motivated health workers but also on their equitable distribution.[13 15] The uneven distribution of health staff is a serious and longstanding global problem, especially for the imbalanced distribution across countries and territories.[16 17] One study found that the Americas, which comprises 37% of the global health workforce, has only 10% of the global burden of disease.[17] In contrast, sub-Saharan Africa has more than 24% of the global burden of disease but only 3% of the global health workforce.[17 18] Population mortality rates can be affected by factors both internal and external to the health workforce,[4 8 19 20] including productivity level, healthcare conditions, education level, social welfare policies, and natural disasters. An econometric study showed that higher density of a health workforce, particularly of total skilled health workers and nursing and midwifery staff, was substantially correlated with a lower maternal mortality ratio and mortality rates in under-5s, infants, and neonates, and the higher health workforce density was also significantly associated with lower excess covid-19 deaths per 100 000 population.[4] However, the association between the density of doctors and maternal mortality ratio and mortality rates in under-5s, infants, and neonates was inconsistent in several earlier studies.[21-25] Moreover, no significant results were identified in five cross country studies that investigated the associations between nurse density and maternal mortality ratio and mortality rate in under-5s and infants.[21-23 26 27] The inconsistent results of previous studies may have resulted from the methods, variables, and procedures used.[21-23 26 27]

Although several studies[4 21-27] have analyzed the relation between HRH and mortality rate, studies focusing on inequalities in HRH in association with cause specific mortality from a global perspective are scarce. To help contribute to the promotion of healthy lives and wellbeing and effective universal health coverage, we quantified the associations between HRH and all cause and cause specific mortality in 172 countries and territories representing most of WHO's member states. To provide baseline data for understanding the current distribution of HRH, we also explored the inequalities in HRH from 1990 to 2019.

Methods

Study design and data sources

We collected yearly data on total HRH, specific types of HRH, all cause mortality, and cause specific mortality from 1990 to 2019 at country level from the Global Burden of Disease Results (https://vizhub.healthdata.org/gbd-results/), a widely used database coordinated by the Institute for Health Metrics and Evaluation.[28] Based on the assessment criteria of data quality, to ensure rigor of the data we finally included 172 of the 204 countries and territories (see supplementary table S1). Data on demographic characteristics, socioeconomic status, and health services were obtained from United Nations Statistics (http://data.un.org/) and Our World in Data (https://ourworldindata.org/) to be used as covariates in our models (see supplementary methods for details).[29-31]

Human resources for health

HRH encompasses a range of occupations intended to promote or improve human health.[1-3] We extracted annual data for the densities of both total and specific types of HRH (per 10 000 population) from 1990 to 2019 by location from the Global Burden of Disease Study 2019 (see supplementary table S2).[32] After we had consolidated similar occupations, 16 health worker cadres remained (see supplementary table S4). Doctors, nursing and midwifery staff, dentistry staff, and pharmaceutical staff are highlighted in sustainable development goal 3.c.1.[2 33 34] The Global Burden of Disease Study produced modeled estimates for the missing data points (see supplementary table S3). Briefly, the Institute for Health Metrics and Evaluation systematically extracted data from WHO's Global Health Observatory and representative cross sectional surveys and censuses that sampled general working age populations (defined as ages 15-69) in which respondents self-reported employment status and current occupation.[32] Employment and occupation data for HRH in the Global Burden of Disease Study 2019 were mapped to the International Standard Classification of Occupations-88.[32 35] After the HRH cadres had been split and bias corrections performed, we applied spatiotemporal Gaussian process regression—a flexible three stage modeling approach—to model HRH densities from 1990 to 2019 for all of the countries and territories. This model is widely used in Global Burden of Disease studies, allowing the generation of full time series estimates with uncertainty intervals from data that are usually unevenly distributed in space and time.[35]

All cause and cause specific mortality

In this study we considered age standardized all cause mortality (per 100 000 population) as the primary outcome and 21 age standardized types of cause specific mortality as secondary outcomes (see supplementary table S5). The Global Burden of Disease cause of death database 2019 consists of all available global data extracted from vital registration, verbal autopsy, registry, survey, police report, and surveillance systems (see supplementary table S6).[36-38] To enhance comparability, the Global Burden of Disease group mapped detailed causes (coded according to the international classification of diseases) and redistributed garbage codes to the Global Burden of Disease cause list (levels 1-4).[37] After several steps of data correction, we modeled processed data using standardized tools to generate estimates of mortality. Cause of Death Ensemble modeling (CODEm), a highly systematized tool with four families of statistical models, was the framework used to model most of the cause specific death rates in the Global Burden of Disease. We used DisMod-MR 2.1, negative binomial models, natural history models, sub-cause proportion models, and prevalence based models to model a subset of causes of death with unique epidemiology, large changes in reporting over time, or particularly limited data availability.[37] For all cause mortality, we mainly used spatiotemporal Gaussian process regression to synthesize data sources after correction for known biases and to estimate the mortality rate (see supplementary methods).[36 37 39]

Statistical analysis

We compared demographic information, socioeconomics, and health resources among 172 countries and territories within different levels of HRH (lowest, low, middle, high, and highest) using median and interquartile range. Estimated annual percentage change was calculated by fitting the regression line: $y=\alpha+\beta x+\varepsilon$, where β represents the annual change in ln(HRH density or mortality rate).[40] We calculated estimated annual percentage change as $100\times(e^{\beta}-1)$ to assess the temporal trend of the HRH density and mortality rate, along with corresponding 95% confidence intervals.[41-43] If annual percentage change estimates and 95% confidence intervals were both >0 (or both <0), we considered the corresponding rate to be in an upward (or downward) trend.

We applied the Lorenz curve and the concentration index (CCI) to indicate the unequal distribution among countries with different development levels based on the human development index. The greater the deviation of the Lorenz curve from the diagonal line, the more marked the inequality. CCI is defined as twice the area between the curve and the diagonal, which ranges from −1 to 1. A positive CCI value indicates that HRH is distributed in the group ranked

Table 1 | Characteristics of demographics, socioeconomic status, and health services by different levels of human resources for health in 172 countries and territories, 1990-2019. Values are median (interquartile range) unless stated otherwise

Characteristics	Total	HRH levels: Lowest	Low	Middle	High	Highest	P value*
Demographic							
Population density (people per km^2)	82.2 (35.3-181.0)	61.0 (34.7-134.1)	78.6 (34.6-143.2)	79.4 (34.3-158.9)	94.5 (46.1-169.6)	112.3 (23.5-258.3)	<0.001
Population living in urban areas (%)	58.5 (40.6-77.3)	31.6 (18.9-44.4)	45.5 (32.8-58.6)	58.1 (49.8-73.9)	68.9 (58.2-84.9)	82.4 (74.1-91.5)	<0.001
Average years of schooling (years)	8.0 (5.6-10.1)	3.4 (2.3-4.5)	6.5 (5.3-7.9)	8.2 (7.3-9.5)	9.3 (8.1-10.7)	11.2 (9.6-12.1)	<0.001
Sociodemographic index	0.6 (0.5-0.7)	0.3 (0.2-0.4)	0.5 (0.4-0.6)	0.6 (0.6-0.7)	0.7 (0.7-0.8)	0.8 (0.8-0.8)	<0.001
Socioeconomic status							
GDP per capita†	10 990.6 (4661.8-25 076.6)	2085.0 (1414.9-3476.7)	6242.4 (3965.8-8943.1)	11 424.6 (8725.5-14 712.0)	19 247.7 (13 532.2-29 694.6)	40 414.4 (30 046.8-51 875.3)	<0.001
Human development index	0.7 (0.6-0.8)	0.4 (0.4-0.5)	0.6 (0.6-0.7)	0.7 (0.7-0.7)	0.8 (0.7-0.8)	0.9 (0.8-0.9)	<0.001
HRH (workers per 10 000 population)							
Total	89.7 (38.4-186.9)	21.0 (16.0-25.7)	46.1 (38.4-54.3)	89.7 (75.9-106.3)	163.4 (145.1-186.9)	338.1 (274.5-442.1)	<0.001
Cadres:							
Doctors	11.8 (4.6-23.3)	1.8 (1.0-3.8)	6.3 (3.7-9.1)	12.3 (7.8-17.4)	18.8 (13.4-26.8)	32.5 (25.7-39.8)	<0.001
Nursing and midwifery staff	33.0 (14.4-62.2)	8.2 (5.5-11.3)	18.9 (13.9-24.6)	33.8 (23.3-43.8)	56.0 (46.5-68.0)	108.9 (81.7-140.8)	<0.001
Dentistry staff	4.2 (0.9-9.5)	0.2 (0.1-0.4)	1.3 (0.7-2.6)	4.5 (2.3-6.8)	8.5 (5.2-10.7)	12.5 (9.7-16.3)	<0.001
Pharmaceutical staff	4.4 (1.6-10.1)	0.6 (0.4-1.4)	2.3 (1.2-3.4)	4.4 (2.5-6.4)	8.0 (5.2-11.8)	14.4 (10.4-18.4)	<0.001
Medical assistants and CHWs	2.5 (1.2-5.5)	1.2 (0.8-1.6)	1.6 (0.7-2.1)	2.5 (1.1-4.0)	4.3 (3.0-7.7)	8.1 (5.2-12.9)	<0.001
Aides and emergency medical workers	6.7 (2.1-25.2)	1.3 (0.7-2.2)	2.4 (1.3-4.2)	6.5 (3.7-10.5)	19.9 (13.2-28.4)	69.2 (39.8-107.6)	<0.001
Medical laboratory technicians	2.3 (0.8-5.0)	0.3 (0.2-0.6)	1.1 (0.6-1.8)	2.4 (1.6-3.4)	4.0 (2.9-6.1)	8.9 (5.2-12.2)	<0.001
Dietitians and nutritionists	1.0 (0.2-2.7)	0.1 (0.0-0.2)	0.4 (0.2-0.8)	1.1 (0.6-1.9)	2.3 (1.3-3.7)	3.8 (2.5-6.4)	<0.001
Optometrists	0.5 (0.1-2.1)	0.1 (0.0-0.1)	0.2 (0.1-0.3)	0.5 (0.2-1.2)	1.5 (0.8-2.8)	3.5 (2.3-5.0)	<0.001
Audiologists and counsellors	1.7 (0.6-4.3)	0.3 (0.1-0.8)	0.7 (0.3-1.5)	1.8 (1.0-2.9)	3.9 (2.4-5.9)	6.4 (4.3-9.4)	<0.001
Psychologists	2.2 (0.4-5.8)	0.2 (0.1-0.3)	0.6 (0.3-1.1)	2.3 (1.3-3.7)	4.8 (3.4-7.1)	9.5 (6.8-13.5)	<0.001
Environmental health officers	2.1 (0.6-4.4)	0.5 (0.3-0.7)	1.0 (0.5-2.0)	2.8 (1.0-4.4)	3.7 (1.9-6.5)	4.6 (3.4-7.3)	<0.001
Personal care workers	2.8 (0.7-9.6)	0.3 (0.1-0.8)	1.1 (0.4-2.4)	2.4 (1.1-4.7)	6.5 (3.8-11.5)	20.7 (11.3-32.7)	<0.001
Traditional and complementary medicine practitioners	1.4 (0.6-2.5)	1.6 (0.6-2.9)	1.1 (0.4-2.0)	1.0 (0.5-1.7)	1.4 (0.7-2.3)	2.5 (1.3-4.7)	<0.001
Physiotherapists	2.8 (0.4-7.4)	0.1 (0.1-0.3)	0.7 (0.3-1.9)	3.1 (1.5-5.4)	5.6 (3.3-8.8)	11.5 (7.8-18.1)	<0.001
Radiographers	0.9 (0.3-2.7)	0.2 (0.1-0.3)	0.4 (0.2-0.7)	0.8 (0.4-1.3)	1.9 (1.2-3.3)	5.4 (3.6-7.9)	<0.001

CHWs=community health workers; GDP=gross domestic product; HRH=human resources for health.
All P values <0.05.
*Test for trends for different HRH levels for demographic and socioeconomic characteristics, and for HRH variables for 1990 to 2019.
†Constant 2017 international $.

Table 2 | Trends in human resources for health density stratified by cadre in 172 countries and territories, 1990-2019. Values are median (interquartile range) unless stated otherwise

HRH (workers per 10 000 population)	HRH density		EAPC (%, 95% CI)	P value*
	1990	2019		
Total	56.0 (25.0-127.1)	142.5 (58.5-277.5)	2.9 (2.5 to 3.2)	<0.001
Cadres:				
Doctors	8.3 (3.4-17.2)	17.4 (7.5-30.7)	2.4 (2.0 to 2.8)	<0.001
Nursing and midwifery staff	21.6 (9.6-49.2)	49.3 (22.3-79.0)	2.2 (1.9 to 2.6)	<0.001
Dentistry staff	2.5 (0.5-6.0)	6.5 (2.0-12.0)	3.2 (2.6 to 3.7)	<0.001
Pharmaceutical staff	2.5 (1.0-6.3)	7.0 (2.7-15.1)	3.2 (2.8 to 3.5)	<0.001
Medical assistants and CHWs	1.7 (0.9-4.1)	3.7 (1.8-7.8)	2.6 (2.3 to 2.9)	<0.001
Aides and emergency medical workers	3.8 (1.2-17.3)	11.5 (3.8-41.7)	4.3 (3.8 to 4.8)	<0.001
Medical laboratory technicians	1.2 (0.4-2.8)	3.6 (1.5-7.0)	3.9 (3.5 to 4.3)	<0.001
Dietitians and nutritionists	0.6 (0.1-1.6)	2.0 (0.5-3.8)	4.2 (3.7 to 4.7)	<0.001
Optometrists	0.2 (0.0-1.1)	1.1 (0.3-3.7)	5.3 (4.8 to 5.9)	<0.001
Audiologists and counsellors	1.0 (0.4-2.7)	3.0 (1.0-6.5)	3.2 (2.8 to 3.7)	<0.001
Psychologists	1.2 (0.2-3.2)	4.3 (0.9-9.3)	4.5 (4.0 to 5.1)	<0.001
Environmental health officers	1.7 (0.5-3.5)	3.0 (1.0-5.5)	2.5 (2.1 to 2.9)	<0.001
Personal care workers	1.3 (0.3-4.4)	5.9 (1.7-15.6)	5.0 (4.4 to 5.6)	<0.001
Traditional and complementary medicine practitioners	1.2 (0.5-2.2)	1.8 (0.9-3.0)	1.5 (1.2 to 1.8)	<0.001
Physiotherapists	1.5 (0.2-4.7)	5.7 (0.9-11.0)	4.4 (3.9 to 5.0)	<0.001
Radiographers	0.4 (0.2-1.5)	1.5 (0.5-4.5)	3.8 (3.4 to 4.3)	<0.001

CI=confidence interval; CHW=community health worker; EAPC=estimated annual percentage change; HRH=human resources for health.
*P for trend <0.05.

higher on the human development index, whereas a negative value indicates the opposite. The closer to 0 the CCI is, the more equitable is the allocation of resources.[44] To assess the association between HRH (total and 16 types) and mortality rates (all cause and 21 cause specific), we applied the generalized estimating equation model, a widely used linear model for longitudinal data analysis with repeated measures over time.[45] The generalized estimating equation model used a gamma distribution and log-link function to control for the skewed nature of mortality. The dependent variable refers to ln(age standardized mortality rate). In the univariable model, after controlling for the effect of time, we explored the association between HRH and mortality rates using crude incidence risk ratios and corresponding 95% confidence intervals. In multivariable models, we controlled for year, population density, percentage of the population living in urban areas, average years of schooling, gross domestic product per capita, and ranking on the human development index. To test the robustness of the results, in sensitivity analyses we replaced the human development index with the socioeconomic index. STATA version 13.0 and SPSS version 23.0 were used in this study, and statistical significance was attributed to two sided P values <0.05. For more details on the statistical analysis, see the methods section in the supplementary file.

Patient and public involvement

Being involved in the Global Burden of Disease 2019 and other open databases rather than directly speaking to patients inspired this research. Although no patient was directly involved in this study, members of the public read our manuscript, and all agreed on the specific findings of this study.

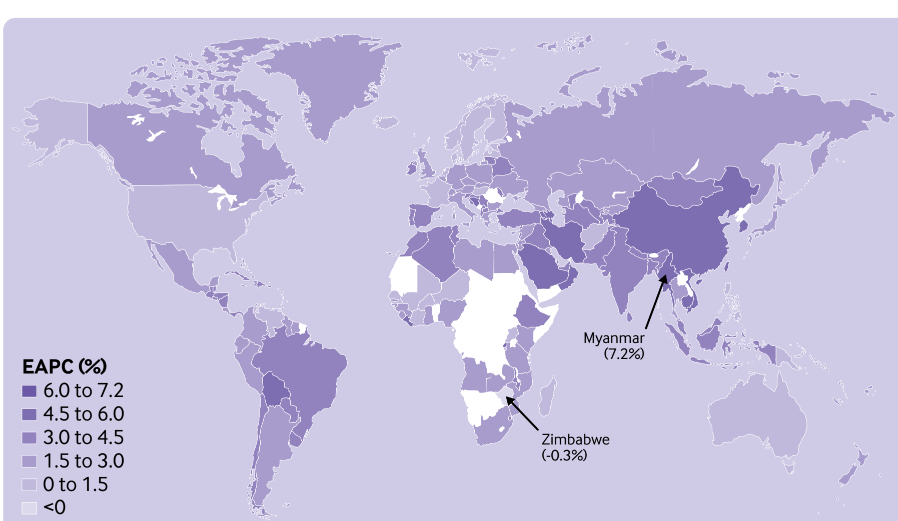

Fig 1 | Estimated annual percentage change (EAPC) in human resources for health per 10 000 population in 172 countries and territories, 1990-2019

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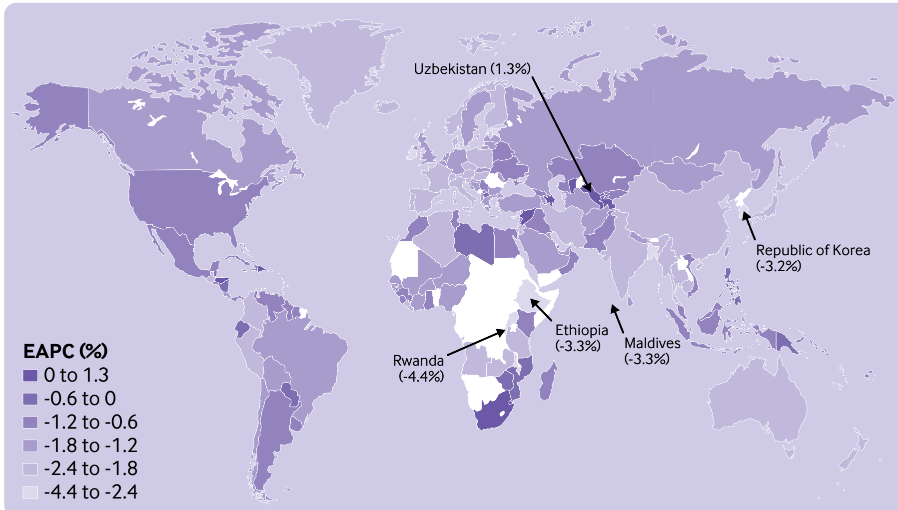


Fig 2 | Estimated annual percentage change (EAPC) in all cause mortality per 100 000 population in 172 countries and territories, 1990-2019

Results

Basic characteristics and different levels of HRH

Countries and territories with higher levels of HRH were likely to have higher population density, a higher percentage of the population living in urban areas, more average years of schooling, and a higher socioeconomic index (all P<0.05) (table 1). For indicators denoting socioeconomic status, gross domestic product per capita and the human development index were also positively changed with the increase of total health workforce. In addition, the total median density of HRH between 1990 and 2019 was 89.7 (interquartile range (IQR) 38.4-186.9) workers per 10 000 population, ranging from 21.0 to 338.1 workers per 10 000 population in countries with different HRH levels. Similar distributions were seen in all 16 HRH cadres.

Trends and inequalities in HRH among 172 countries and territories

Globally, total HRH density increased from 56.0 per 10 000 population in 1990 to 142.5 per 10 000 population in 2019, with an estimated annual percentage change of 2.9% (95% confidence interval 2.5% to 3.2%). A positive estimated annual percentage change was observed in each cadre, ranging from 1.5% for traditional and complementary medicine practitioners to 5.3% for optometrists (table 2). Among 172 countries and territories, the total HRH density in 2019 was distributed unevenly—Sweden had the highest access to HRH per capita (696.1 workers per 10 000 population), whereas Ethiopia and Guinea had less than one ninth of the global HRH level, with 13.9 and 15.1 workers per 10 000 population, respectively (see supplementary table S7). Except for Zimbabwe (−0.3%, −0.6% to 0%), all countries had a positive estimated annual percentage change (P<0.05; fig 1, also see fig 2 for all cause mortality estimates per 100 000 population) and supplementary table S7). Myanmar had the highest estimated annual percentage change in HRH density (7.2%, 6.9% to 7.5%). Supplementary table S8 and supplementary figure S2 display the densities and estimated annual percentage changes in 16 HRH cadres in 172 countries and territories.

The Lorenz curve of health worker density lay below the equality line, with a positive CCI of 0.43 (P<0.05), indicating that the health workforce was more concentrated among countries and territories that ranked high on the human development index (fig 3). Supplementary figure S1 shows the Lorenz curve of all 16 cadres of HRH. The CCI for HRH was stable at about 0.42-0.43 between 1990 and 2001 and continued to decline (narrowed inequality), from 0.43 in 2001 to 0.38 in 2019 (P<0.001, fig 4, supplementary table S9). The CCI of four HRH cadres highlighted in sustainable development goal 3c.1—doctors, nursing and midwifery staff, dentistry staff, and pharmaceutical staff were 0.37, 0.38, 0.43, and 0.41, respectively (P<0.001, supplementary table S10).

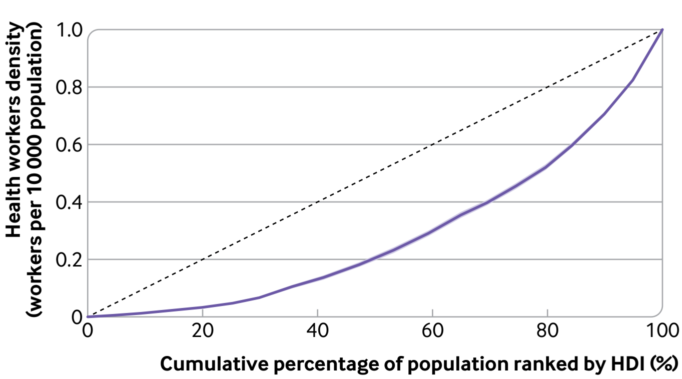


Fig 3 | Lorenz curve of health worker density for human resources for health among 172 countries and territories, 1990-2019. HDI=human development index. Diagonal broken line represents equity line. Shaded area represents 95% confidence interval

Disparities in mortality among 172 countries and territories

The all cause age standardized mortality rate decreased from 995.5 (IQR 790.9-1317.0) per 100 000

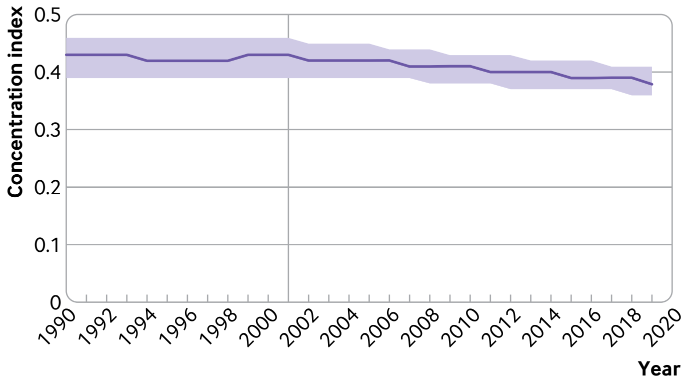


Fig 4 | Trends in concentration index for human resources for health, among 172 countries and territories, 1990-2019. Shaded area represents 95% confidence interval

population in 1990 to 743.8 (539.0-990.9) per 100 000 population in 2019, with an estimated annual percentage change of −1.3% (95% confidence interval −1.4% to −1.2%) (table 3). The age standardized mortality rate in 2019 was highest in the Solomon Islands (1919.9) and lowest in Singapore (324.1) and Japan (323.3) (see supplementary table S11), The estimated annual percentage change differed, from the highest in Uzbekistan (1.3%, 0.8% to 1.8%) to the lowest in the Maldives (−3.3%, −3.5% to −3.0%), Ethiopia (−3.3%, −3.5% to −3.1%), and Rwanda (−4.4%, −5.7% to −3.1%) (fig 2 and supplementary table S11). For the 21 types of cause specific mortality, the number of deaths per 100 000 population declined from 1990 to 2019 for most of the causes, except for deaths due to neurological disorders, mental disorders, skin and subcutaneous diseases, and musculoskeletal disorders (table 3). According to the results shown in supplementary table S12, the mortality rate for HIV/AIDS and sexually transmitted infections increased from 2.0 (95% confidence interval 0.7 to 7.6) per 100 000 population in 1990 to 3.6 (0.7 to 19.1) per 100 000 population in 2000, but then decreased steadily to 3.4 (0.6 to 11.5) per 100 000 population in 2019. The mortality rate increased before 2000 (estimated annual percentage change 7.5%, 95% confidence interval 4.0% to 11.2%) and then declined after 2010 (−2.7%, −5.9% to 0.5%).

Results using generalized estimating equation model

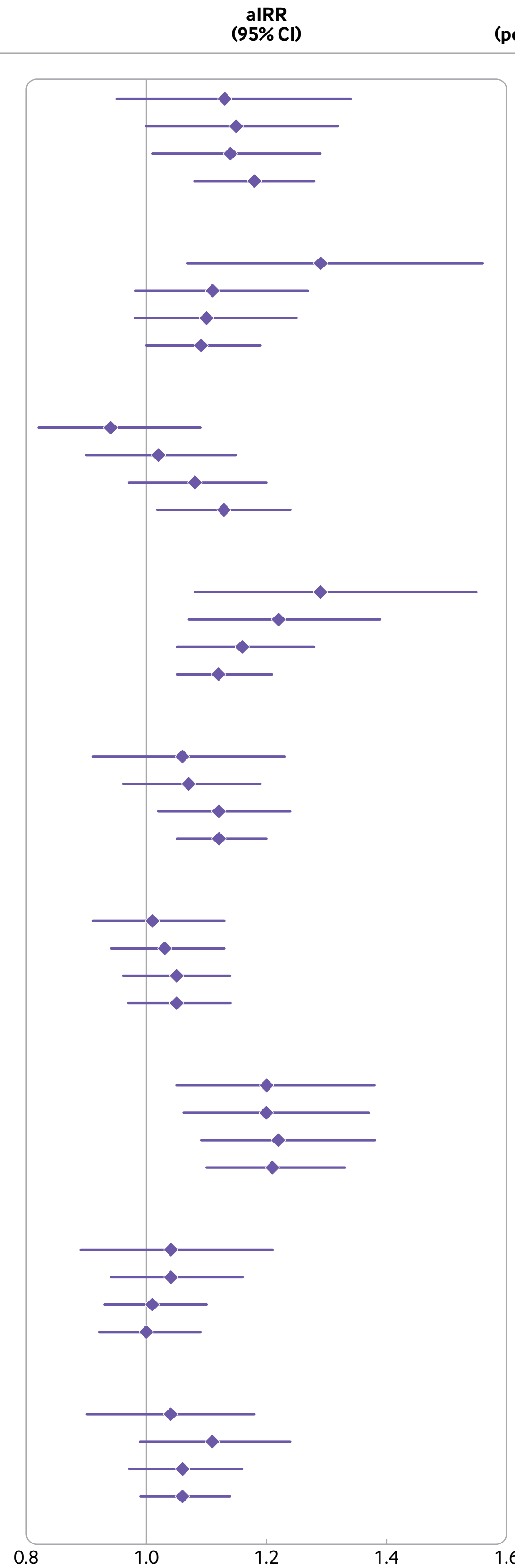
In the multivariable generalized estimating equation model, a negative association was observed between total HRH density and all cause mortality, with the highest HRH levels as reference group (low: adjusted incidence risk ratio 1.15, 95% confidence interval 1.00 to 1.32; middle: 1.14, 1.01 to 1.29; high: 1.18, 1.08 to 1.28) (fig 5, fig 6, and supplementary table S13). The increase in human development index (0.06, 95% confidence interval 0.03 to 0.10) may also be related to the decreased mortality (supplementary table S13). Compared with the Solomon Islands (HRH 42.0, age standardized mortality rate 1919.9), some countries had a very low density of HRH in 2019 but lower all cause mortality, such as Ethiopia (18.2, 993.5), Morocco (32.3, 851.5), and Palestine (34.9, 796.6) (see supplementary figure S19).

In most disease models, negative associations were found between total HRH density and particular types of cause specific mortality, except for HIV/AIDS and sexually transmitted infections, neoplasms,

Table 3 | Trends for all cause and cause specific mortality in 172 countries and territories, 1990-2019

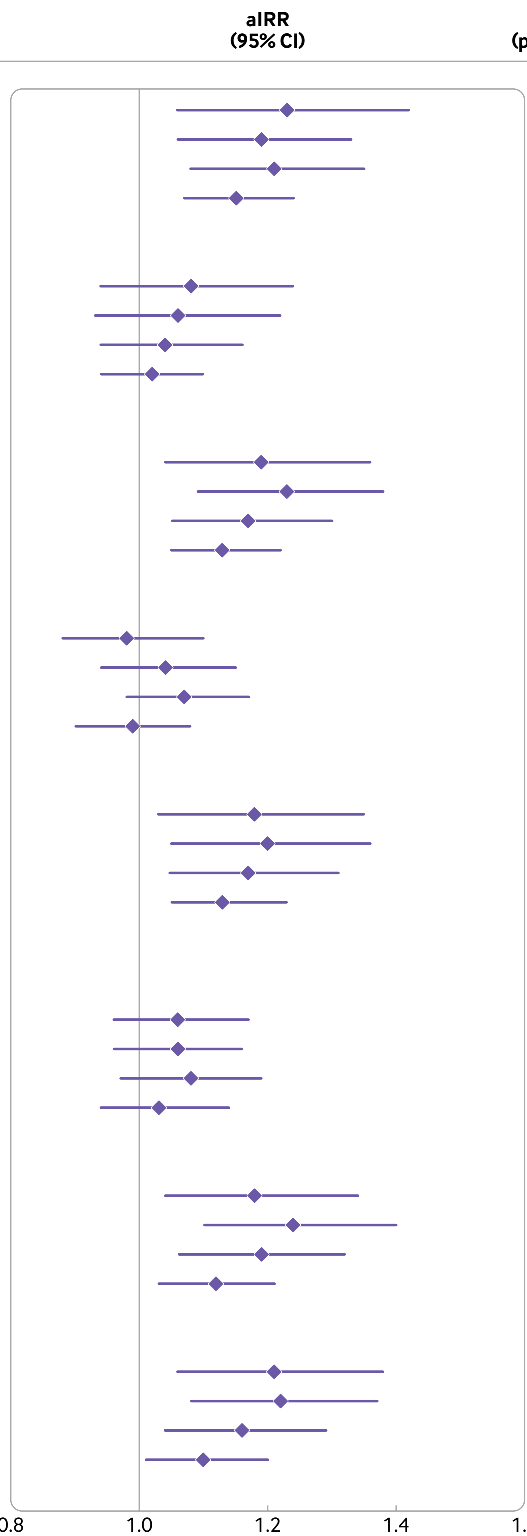
	Age standardized mortality rate (IQR)			
Mortality per 100 000 population	1990	2019	EAPC (%, 95% CI)	P value
All cause	995.5 (790.9-1317.0)	743.8 (539.0-990.9)	−1.3 (−1.4 to −1.2)	<0.001*
Cause specific:				
HIV/AIDS and sexually transmitted infections	2.0 (0.7-7.6)	3.4 (0.6-11.5)	0.3 (−0.4 to 1.0)	0.37
Respiratory infections and tuberculosis	53.8 (31.5-152.4)	30.0 (17.7-77.8)	−2.2 (−2.5 to −1.9)	<0.001*
Enteric infections	9.6 (1.2-45.5)	2.6 (1.0-12.9)	−2.9 (−3.6 to −2.3)	<0.001*
Neglected tropical diseases and malaria	0.7 (0.1-7.4)	0.3 (0.1-2.2)	−3.2 (−4.1 to −2.3)	<0.001*
Other infectious diseases	8.7 (3.0-29.8)	2.7 (1.4-8.8)	−3.7 (−4.1 to −3.3)	<0.001*
Maternal and neonatal disorders	29.7 (13.1-53.0)	10.7 (4.3-25.3)	−2.9 (−3.2 to −2.6)	<0.001*
Nutritional deficiencies	2.9 (0.7-15.8)	1.3 (0.3-4.6)	−3.2 (−3.7 to −2.6)	<0.001*
Neoplasms	138.1 (111.2-164.6)	126.5 (109.2-147.2)	−0.2 (−0.3 to −0.1)	<0.001*
Cardiovascular diseases	346.6 (282.5-466.8)	257.9 (173.5-338.4)	−1.4 (−1.6 to −1.3)	<0.001*
Chronic respiratory diseases	43.3 (28.3-66.6)	28.9 (20.3-44.4)	−1.5 (−1.6 to −1.3)	<0.001*
Digestive diseases	40.8 (29.7-68.0)	32.3 (22.1-52.3)	−1.1 (−1.3 to −0.9)	<0.001*
Neurological disorders	31.0 (28.8-33.2)	31.5 (29.7-33.6)	0.1 (0.0 to 0.1)	<0.001*
Mental disorders	0.001 (0.000-0.002)	0.001 (0.000-0.003)	1.6 (1.1 to 2.0)	<0.001*
Substance use disorders	2.2 (1.4-4.2)	2.1 (1.4-4.6)	−0.3 (−0.6 to 0.0)	0.07
Diabetes and kidney diseases	50.2 (24.7-76.4)	54.0 (24.1-82.4)	0.2 (−0.1 to 0.4)	0.18
Skin and subcutaneous diseases	1.5 (0.4-2.4)	1.7 (0.5-2.6)	0.6 (0.2 to 1.0)	0.002*
Musculoskeletal disorders	1.1 (0.6-1.7)	1.1 (0.8-1.8)	0.4 (0.2 to 0.7)	<0.001*
Other non-communicable diseases	19.5 (14.6-26.3)	14.5 (10.3-20.8)	−1.1 (−1.2 to −0.9)	<0.001*
Transport injuries	22.4 (16.7-30.1)	14.2 (8.5-20.4)	−2.0 (−2.2 to −1.9)	<0.001*
Unintentional injuries	31.1 (21.3-40.6)	18.5 (13.2-27.6)	−1.7 (−1.8 to −1.5)	<0.001*
Self-harm and interpersonal violence	18.9 (12.7-27.7)	14.2 (9.4-23.1)	−1.1 (−1.4 to −0.9)	<0.001*

CI=confidence interval; EAPC=estimated annual percentage change; IQR=interquartile range.
Mortality rate shown as median (IQR).
*P value for trends <0.05.



	All cause mortality (per 100 000 population, IQR)	aIRR (95% CI)
All health workers		
Lowest	1478.8 (1186.2-1824.8)	1.13 (0.95 to 1.34)
Low	1021.4 (815.3-1243.9)	1.15 (1.00 to 1.32)*
Middle	828.5 (682.4-965.5)	1.14 (1.01 to 1.29)*
High	761.8 (642.4-935.9)	1.18 (1.08 to 1.28)*
Highest	541.0 (449.9-655.0)	Reference group
Doctors		
Lowest	1600.2 (1344.3-1872.0)	1.29 (1.07 to 1.56)*
Low	913.9 (813.8-1104.4)	1.11 (0.98 to 1.27)
Middle	805.1 (690.7-1014.6)	1.10 (0.98 to 1.25)
High	736.5 (590.8-918.0)	1.09 (1.00 to 1.19)
Highest	564.7 (464.8-730.2)	Reference group
Nursing and midwifery staff		
Lowest	1384.6 (1007.4-1709.0)	0.94 (0.82 to 1.09)
Low	929.4 (722.0-1295.0)	1.02 (0.90 to 1.15)
Middle	867.5 (691.9-1073.0)	1.08 (0.97 to 1.20)
High	794.9 (627.0-973.5)	1.13 (1.02 to 1.24)*
Highest	561.5 (462.5-725.5)	Reference group
Dentistry staff		
Lowest	1550.4 (1335.7-1846.6)	1.29 (1.08 to 1.55)*
Low	978.4 (843.0-1175.0)	1.22 (1.07 to 1.39)*
Middle	806.5 (682.6-956.7)	1.16 (1.05 to 1.28)*
High	728.1 (579.4-889.4)	1.12 (1.05 to 1.21)*
Highest	570.4 (465.4-722.7)	Reference group
Pharmaceutical staff		
Lowest	1506.6 (1140.1-1844.3)	1.06 (0.91 to 1.23)
Low	962.6 (802.1-1257.5)	1.07 (0.96 to 1.19)
Middle	866.9 (719.3-1063.4)	1.12 (1.02 to 1.24)*
High	740.5 (608.2-945.5)	1.12 (1.05 to 1.20)*
Highest	551.1 (452.3-725.7)	Reference group
Medical assistants and CHWs		
Lowest	1080.7 (878.0-1602.7)	1.01 (0.91 to 1.13)
Low	1171.7 (795.9-1578.5)	1.03 (0.94 to 1.13)
Middle	924.5 (693.0-1190.6)	1.05 (0.96 to 1.14)
High	707.1 (563.1-897.3)	1.05 (0.97 to 1.14)
Highest	650.5 (486.1-830.1)	Reference group
Aides and emergency medical workers		
Lowest	1264.4 (971.2-1655.9)	1.20 (1.05 to 1.38)*
Low	1104.6 (834.9-1484.3)	1.20 (1.06 to 1.37)*
Middle	868.3 (712.1-1087.2)	1.22 (1.09 to 1.38)*
High	744.4 (618.1-922.6)	1.21 (1.10 to 1.33)*
Highest	543.2 (451.2-665.4)	Reference group
Medical lab technicians		
Lowest	1550.3 (1227.2-1847.6)	1.04 (0.89 to 1.21)
Low	1001.0 (843.8-1295.4)	1.04 (0.94 to 1.16)
Middle	796.6 (672.3-957.7)	1.01 (0.93 to 1.10)
High	717.7 (574.0-880.8)	1.00 (0.92 to 1.09)
Highest	595.0 (478.3-793.8)	Reference group
Dietitians and nutritionists		
Lowest	1464.9 (1167.5-1826.1)	1.04 (0.90 to 1.18)
Low	1010.2 (818.7-1346.0)	1.11 (0.99 to 1.24)
Middle	820.2 (654.8-980.4)	1.06 (0.97 to 1.16)
High	714.4 (569.6-873.4)	1.06 (0.99 to 1.14)
Highest	604.9 (476.9-779.5)	Reference group

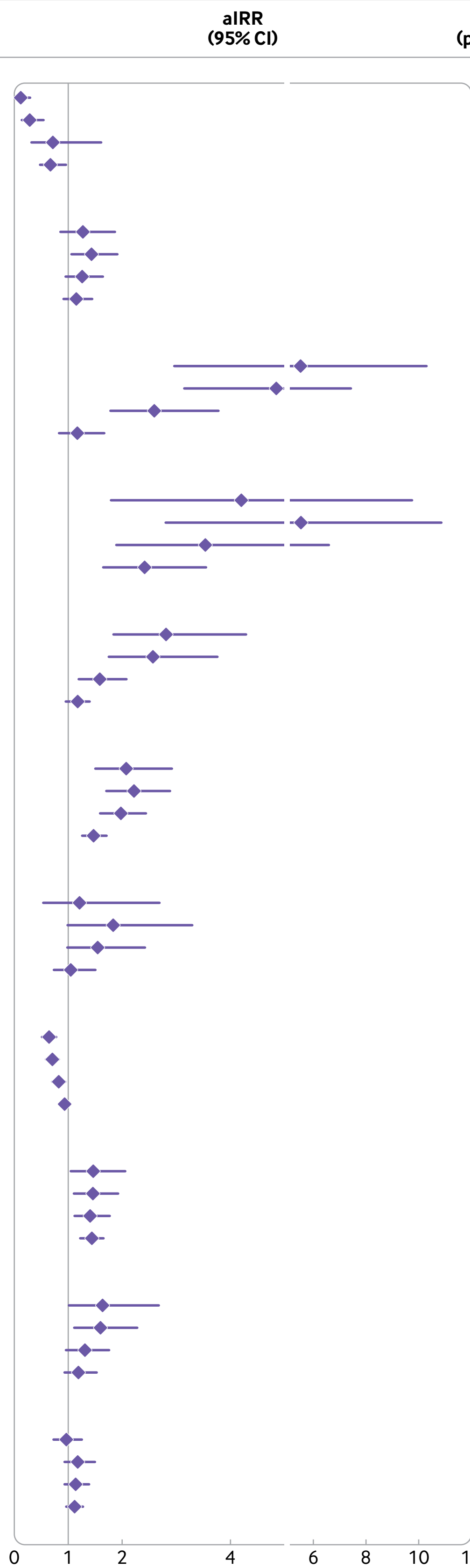
Fig 5 | Multivariable generalized estimating equation models showing association between human resources for health and all cause mortality for all health workers and eight of 16 cadres (see fig 6 for the other eight cadres in the current study) in 172 countries and territories, 1990-2019. Multivariable models were adjusted for health worker densities, year, population density, percentage of population living in urban areas, average years of schooling, gross domestic product per capita, and ranking on the human development index. aIRR=adjusted incidence risk ratio; CHWs=community health workers; CI=confidence interval; IQR=interquartile range. *P<0.05



	All cause mortality (per 100 000 population, IQR)	aIRR (95% CI)
Optometrists		
Lowest	1403.8 (1064.2-1821.8)	1.23 (1.06 to 1.42)*
Low	1043.1 (829.4-1405.0)	1.19 (1.06 to 1.33)*
Middle	844.2 (697.2-1087.5)	1.21 (1.08 to 1.35)*
High	716.8 (592.0-903.6)	1.15 (1.07 to 1.24)*
Highest	562.5 (464.3-728.2)	Reference group
Audiologists and counsellors		
Lowest	1122.7 (856.1-1574.5)	1.08 (0.94 to 1.24)
Low	1147.1 (753.9-1583.7)	1.06 (0.93 to 1.22)
Middle	890.4 (699.2-1149.9)	1.04 (0.94 to 1.16)
High	736.0 (583.4-905.0)	1.02 (0.94 to 1.10)
Highest	626.5 (471.4-855.1)	Reference group
Psychologists		
Lowest	1448.1 (1106.0-1820.7)	1.19 (1.04 to 1.36)*
Low	1093.3 (843.3-1365.9)	1.23 (1.09 to 1.38)*
Middle	845.1 (693.0-1014.0)	1.17 (1.05 to 1.30)*
High	704.8 (573.5-892.5)	1.13 (1.05 to 1.22)*
Highest	578.9 (465.2-723.0)	Reference group
Environmental health officers		
Lowest	1391.3 (1054.7-1735.1)	0.98 (0.88 to 1.10)
Low	988.7 (755.1-1387.2)	1.04 (0.94 to 1.15)
Middle	827.4 (682.6-1056.2)	1.07 (0.98 to 1.17)
High	690.2 (531.6-890.3)	0.99 (0.90 to 1.08)
Highest	695.0 (528.4-870.9)	Reference group
Staff care workers		
Lowest	1210.8 (895.8-1660.9)	1.18 (1.03 to 1.35)*
Low	1087.2 (800.2-1470.8)	1.20 (1.05 to 1.36)*
Middle	927.2 (738.2-1172.6)	1.17 (1.05 to 1.31)*
High	786.3 (649.1-931.4)	1.13 (1.05 to 1.23)*
Highest	553.6 (459.3-670.9)	Reference group
Traditional and complementary medicine practitioners		
Lowest	901.5 (744.2-1087.9)	1.06 (0.96 to 1.17)
Low	850.7 (672.1-1055.2)	1.06 (0.96 to 1.16)
Middle	868.5 (612.9-1221.2)	1.08 (0.97 to 1.19)
High	884.4 (670.3-1282.4)	1.03 (0.94 to 1.14)
Highest	731.0 (518.1-1426.3)	Reference group
Physiotherapists		
Lowest	1402.1 (1065.8-1769.2)	1.18 (1.04 to 1.34)*
Low	1106.0 (843.8-1444.1)	1.24 (1.10 to 1.40)*
Middle	850.0 (701.4-991.8)	1.19 (1.06 to 1.32)*
High	706.8 (582.2-885.4)	1.12 (1.03 to 1.21)*
Highest	574.3 (466.3-741.8)	Reference group
Radiographers		
Lowest	1438.5 (1049.1-1825.0)	1.21 (1.06 to 1.38)*
Low	1027.5 (836.7-1395.5)	1.22 (1.08 to 1.37)*
Middle	855.2 (694.3-1061.3)	1.16 (1.04 to 1.29)*
High	726.9 (614.6-890.4)	1.10 (1.01 to 1.20)*
Highest	547.7 (456.4-679.4)	Reference group

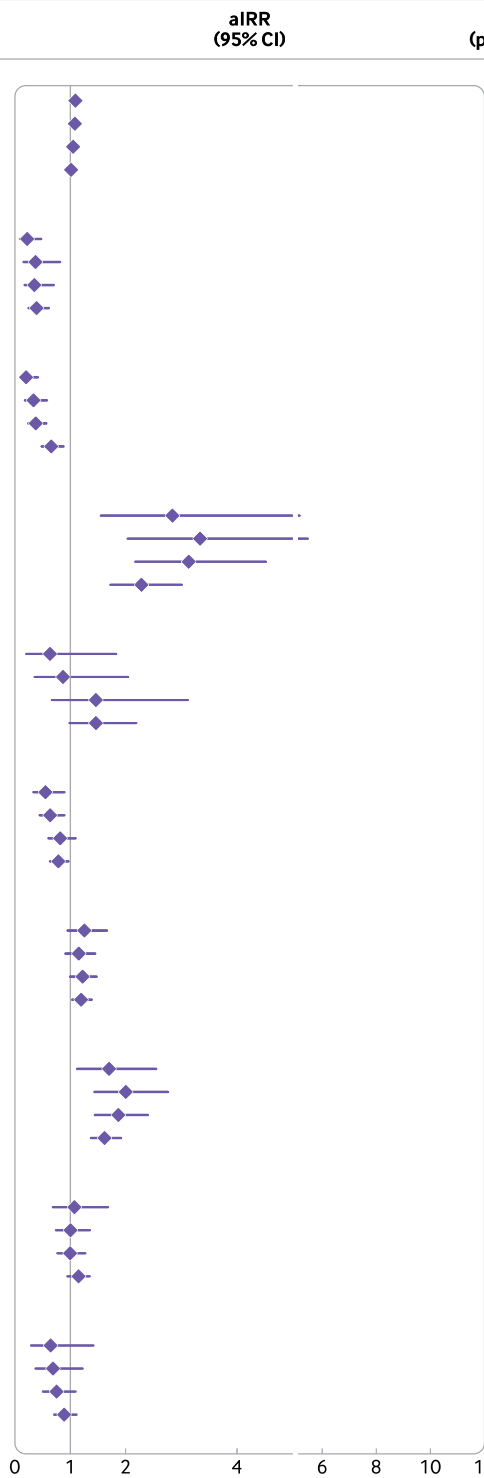
Fig 6 | Multivariable generalized estimating equation models showing association between human resources for health and all cause mortality for eight of 16 cadres (see fig 5 for the other eight cadres in the current study) in 172 countries and territories, 1990-2019. Multivariable models were adjusted for health worker densities, year, population density, percentage of population living in urban areas, average years of schooling, gross domestic product per capita, and ranking on the human development index. aIRR=adjusted incidence risk ratio; CI=confidence interval; IQR=interquartile range. *P<0.05

mental disorders, substance use disorders, and musculoskeletal disorders (fig 7 and fig 8). The risk of death due to enteric infections (lowest: adjusted incidence risk ratio 5.52, 95% confidence interval 2.95 to 10.33; low: 4.84, 3.15 to 7.43), neglected tropical diseases and malaria (lowest: 4.19, 1.81 to 9.74; low:



	Cause specific mortality (per 100 000 population, IQR)	aIRR (95% CI)
HIV/AIDS and sexually transmitted infections		
Lowest	35.18 (3.69-107.89)	0.12 (0.05 to 0.30)*
Low	4.20 (1.09-23.96)	0.29 (0.15 to 0.55)*
Middle	3.73 (1.23-9.03)	0.72 (0.33 to 1.61)
High	2.01 (0.58-5.45)	0.68 (0.49 to 0.96)*
Highest	0.81 (0.39-2.77)	Reference group
Respiratory infections and tuberculosis		
Lowest	211.95 (121.75-282.56)	1.27 (0.86 to 1.87)
Low	69.14 (39.46-156.94)	1.43 (1.06 to 1.91)*
Middle	36.98 (23.80-62.24)	1.26 (0.96 to 1.65)
High	28.45 (19.57-42.69)	1.15 (0.92 to 1.44)
Highest	19.43 (13.19-28.23)	Reference group
Enteric infections		
Lowest	111.25 (53.32-165.03)	5.52 (2.95 to 10.33)*
Low	17.52 (5.74-57.90)	4.84 (3.15 to 7.43)*
Middle	4.15 (1.83-9.12)	2.59 (1.78 to 3.77)*
High	1.39 (0.38-3.17)	1.18 (0.83 to 1.67)
Highest	0.77 (0.39-1.54)	Reference group
Neglected tropical diseases and malaria		
Lowest	46.01 (4.80-141.69)	4.19 (1.81 to 9.74)*
Low	1.62 (0.53-6.95)	5.53 (2.81 to 10.88)*
Middle	0.39 (0.16-0.83)	3.53 (1.89 to 6.58)*
High	0.12 (0.05-0.36)	2.41 (1.64 to 3.54)*
Highest	0.02 (0.01-0.06)	Reference group
Other infectious diseases		
Lowest	45.44 (26.12-71.36)	2.81 (1.85 to 4.28)*
Low	10.42 (5.52-22.88)	2.57 (1.76 to 3.76)*
Middle	3.80 (2.37-6.37)	1.58 (1.20 to 2.08)*
High	2.36 (1.37-3.79)	1.18 (0.98 to 1.41)
Highest	1.34 (1.03-1.92)	Reference group
Maternal and neonatal disorders		
Lowest	62.54 (48.47-78.88)	2.08 (1.49 to 2.91)*
Low	31.37 (22.73-45.85)	2.22 (1.71 to 2.88)*
Middle	18.31 (11.99-27.36)	1.97 (1.59 to 2.43)*
High	10.00 (6.48-15.51)	1.47 (1.27 to 1.71)*
Highest	4.49 (3.22-6.14)	Reference group
Nutritional deficiencies		
Lowest	16.86 (7.66-37.26)	1.21 (0.55 to 2.69)
Low	5.67 (1.71-14.62)	1.83 (1.02 to 3.29)*
Middle	2.17 (0.53-5.15)	1.55 (0.99 to 2.42)
High	0.66 (0.20-2.40)	1.05 (0.74 to 1.50)
Highest	0.38 (0.16-0.76)	Reference group
Neoplasms		
Lowest	110.25 (92.57-133.39)	0.65 (0.53 to 0.78)*
Low	113.80 (99.06-136.17)	0.70 (0.61 to 0.81)*
Middle	132.04 (111.92-159.70)	0.83 (0.73 to 0.94)*
High	155.43 (130.90-174.85)	0.94 (0.87 to 1.02)
Highest	151.69 (137.08-167.89)	Reference group
Cardiovascular diseases		
Lowest	328.65 (288.24-417.79)	1.47 (1.05 to 2.05)*
Low	332.63 (259.51-436.44)	1.46 (1.11 to 1.92)*
Middle	298.78 (216.80-426.80)	1.41 (1.13 to 1.77)*
High	297.45 (231.39-448.12)	1.44 (1.24 to 1.66)*
Highest	185.00 (139.93-263.85)	Reference group
Chronic respiratory diseases		
Lowest	57.43 (44.01-78.13)	1.64 (1.01 to 2.68)*
Low	48.03 (30.92-67.19)	1.60 (1.12 to 2.28)*
Middle	32.81 (24.16-50.84)	1.31 (0.97 to 1.76)
High	28.13 (20.05-37.16)	1.20 (0.94 to 1.53)
Highest	21.04 (16.51-30.42)	Reference group
Digestive diseases		
Lowest	70.16 (57.65-83.35)	0.96 (0.73 to 1.25)
Low	52.06 (33.54-71.92)	1.18 (0.94 to 1.49)
Middle	35.73 (28.25-50.13)	1.14 (0.94 to 1.38)
High	33.14 (25.40-41.04)	1.12 (0.99 to 1.27)
Highest	23.30 (18.32-29.35)	Reference group

Fig 7 | Multivariable generalized estimating equation models showing association between human resources for health and 11 types of cause specific mortality (see figure 8 for other 10 types in the current study) in 172 countries and territories, 1990-2019. Models were adjusted for health worker densities, year, population density, percentage of population living in urban areas, average years of schooling, gross domestic product per capita, and ranking on human development index. aIRR=adjusted incidence risk ratio; CI=confidence interval; IQR=interquartile range. *P<0.05



	Cause specific mortality (per 100 000 population, IQR)	aIRR (95% CI)
Neurological disorders		
Lowest	32.93 (30.69-35.29)	1.10 (1.01 to 1.19)*
Low	32.19 (30.30-34.19)	1.08 (1.02 to 1.15)*
Middle	31.13 (29.82-33.28)	1.05 (1.00 to 1.10)*
High	30.69 (29.29-32.89)	1.02 (0.99 to 1.05)
Highest	30.88 (29.78-32.00)	Reference group
Mental disorders		
Lowest	0.0005 (0.0004-0.0007)	0.23 (0.11 to 0.47)*
Low	0.0009 (0.0003-0.0013)	0.38 (0.17 to 0.82)*
Middle	0.0008 (0.0004-0.0020)	0.36 (0.19 to 0.71)*
High	0.0014 (0.0004-0.0033)	0.40 (0.26 to 0.61)*
Highest	0.0092 (0.0012-0.0169)	Reference group
Substance use disorders		
Lowest	1.79 (1.41-2.18)	0.21 (0.11 to 0.42)*
Low	1.83 (1.38-3.75)	0.34 (0.19 to 0.59)*
Middle	2.15 (1.34-4.31)	0.38 (0.25 to 0.57)*
High	2.77 (1.57-6.38)	0.66 (0.49 to 0.88)*
Highest	4.62 (1.97-6.66)	Reference group
Diabetes and kidney diseases		
Lowest	68.40 (59.99-87.06)	2.83 (1.55 to 5.17)*
Low	66.84 (44.89-89.49)	3.33 (2.03 to 5.48)*
Middle	56.59 (38.03-103.22)	3.13 (2.18 to 4.51)*
High	38.78 (21.73-81.41)	2.28 (1.73 to 3.01)*
Highest	19.14 (14.09-25.80)	Reference group
Skin and subcutaneous diseases		
Lowest	1.96 (1.62-2.35)	0.64 (0.22 to 1.82)
Low	1.68 (0.47-2.91)	0.87 (0.37 to 2.04)
Middle	1.52 (0.42-3.70)	1.46 (0.68 to 3.11)
High	1.31 (0.30-3.57)	1.46 (0.98 to 2.19)
Highest	0.91 (0.39-1.67)	Reference group
Musculoskeletal disorders		
Lowest	0.82 (0.64-1.16)	0.56 (0.35 to 0.89)*
Low	0.89 (0.66-1.45)	0.64 (0.45 to 0.90)*
Middle	1.26 (0.80-2.05)	0.82 (0.62 to 1.09)
High	1.21 (0.47-1.69)	0.79 (0.65 to 0.96)*
Highest	1.39 (0.97-2.21)	Reference group
Other non-communicable diseases		
Lowest	27.02 (21.33-33.20)	1.25 (0.95 to 1.66)
Low	17.99 (14.76-22.66)	1.16 (0.92 to 1.45)
Middle	17.02 (12.98-21.56)	1.22 (1.00 to 1.47)*
High	15.44 (10.96-19.88)	1.20 (1.04 to 1.39)*
Highest	11.24 (8.70-13.21)	Reference group
Transport injuries		
Lowest	25.36 (19.33-32.76)	1.70 (1.13 to 2.55)*
Low	20.47 (14.67-30.20)	2.00 (1.45 to 2.76)*
Middle	19.10 (12.40-25.16)	1.86 (1.44 to 2.40)*
High	16.50 (12.71-21.61)	1.62 (1.38 to 1.91)*
Highest	9.40 (6.76-13.18)	Reference group
Unintentional injuries		
Lowest	38.63 (31.80-44.96)	1.08 (0.70 to 1.67)
Low	29.22 (21.14-36.37)	1.01 (0.75 to 1.35)
Middle	22.71 (16.61-29.66)	1.00 (0.78 to 1.27)
High	21.29 (14.65-28.58)	1.15 (0.97 to 1.36)
Highest	14.78 (11.50-19.60)	Reference group
Self-harm and interpersonal violence		
Lowest	20.44 (13.97-30.72)	0.65 (0.30 to 1.41)
Low	17.10 (10.06-29.39)	0.69 (0.39 to 1.22)
Middle	16.36 (10.85-26.20)	0.76 (0.53 to 1.09)
High	17.50 (10.73-25.69)	0.89 (0.71 to 1.11)
Highest	13.37 (10.18-18.38)	Reference group

Fig 8 | Multivariable generalized estimating equation models showing associations between human resources for health and 10 types of cause specific mortality (see figure 7 for other 11 types in the current study) in 172 countries and territories, 1990-2019. Models were adjusted for health worker densities, year, population density, percentage of population living in urban areas, average years of schooling, gross domestic product per capita, and human development index. aIRR=adjusted incidence risk ratio; CI=confidence interval; IQR=interquartile range. *P<0.05

5.53, 2.81 to 10.88), diabetes and kidney diseases (lowest: 2.83, 1.55 to 5.17; low: 3.33, 2.03 to 5.48), and maternal and neonatal disorders (lowest: 2.08, 1.49 to 2.91; low: 2.22, 1.71 to 2.88) was much higher in areas with low or the lowest HRH density than in areas with the highest HRH density (fig 7 and fig 8).

Subgroup analysis: specific types of HRH density and mortality

Figure 5 and figure 6 show the association between 16 cadres of HRH and all cause mortality, with the highest group as reference. People in countries and territories with a lower density of doctors, dentistry

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staff, pharmaceutical staff, aides and emergency medical workers, optometrists, psychologists, personal care workers, physiotherapists, and radiographers appeared to be at higher risk of death. The associations between both total and specific HRH density and all cause mortality were similar in sensitivity analysis (see supplementary table S15).

When both HRH density and mortality were divided into specific groups, strong negative associations were found for most of the 16 cadres of HRH and cause specific mortality (see supplementary figures S3-S18). The risk of death due to HIV/AIDS and sexually transmitted infections significantly increased in areas with a lower per capita number of doctors (lowest: adjusted incidence risk ratio 18.01, 6.14 to 52.89; low: 5.19, 10.32 to 20.45), dentistry staff (lowest: 6.02, 2.10 to 17.28), and pharmaceutical staff (lowest: 3.49, 1.31 to 9.25; low: 3.24, 1.68 to 6.27; middle: 3.97, 1.09 to 3.15). The association between cadres of doctors, nursing and midwifery staff, pharmaceutical staff, dietitians and nutritionists, and medical laboratory technicians and a reduction in mortality from neglected tropical diseases and malaria was noticeable. When general medical staff were excluded from analysis, a lower density of dentistry staff, aides and emergency medical workers, psychologists, and personal care workers was associated with increased maternal and neonatal disease related mortality. In addition, the increase in mortality from diabetes and kidney diseases seemed to be influenced to some extent by inadequate numbers of optometrists, psychologists, personal care workers, and radiographers.

Discussion

Integrating data from the Global Burden of Disease database, we found inequalities in the distribution of HRH and that this inequality was concentrated in countries and territories with a higher ranking on the human development index. Inequalities have also decreased over time. Using the highest HRH rank as reference, we found a negative association between total HRH density and all cause mortality and most types of cause specific mortality in generalized estimating equation models. Results from subgroup analysis indicated a strong association between lower HRH density and higher cause specific mortality across different HRH cadres and most of the cause specific mortality investigated in the current study. These findings outline the current inequalities in HRH globally and the potential risk of mortality. Countries and territories are supposed to improve HRH based on national conditions, especially for particular cadres of HRH, contributing to achievement of universal health coverage by 2030.

Inequalities and current status of HRH

Inequity in HRH has been a longstanding critical international issue.[16 17 46] In the current study, we found that the health workforce tended to be concentrated in countries and territories that ranked higher on the human development index. Inadequate health financing, low education levels, lack of employment opportunities, war, and violence against health workers are possible factors contributing to this inequality.[47-50] The Global Burden of Disease super regions of sub-Saharan Africa, South Asia, North Africa, and the Middle East were the most prominent regions with low density HRH, confirming our findings.[2] A reasonable population capacity is favorable to promoting sustainable development. Since the overall population carrying capacity varies between countries, without clear and appropriate fertility planning and economic development schemes, countries with an excessively large population may have collapsed economies, healthcare, education, and other sectors.[51-54] According to our findings, Myanmar had the highest estimated annual percentage change at 7.2% in HRH density—the governing party had accelerated the systemic strengthening of healthcare with economic and non-economic incentives, including social recognition and career development.[55 56] Despite the high estimated annual percentage change in Myanmar, the HRH density remained low, at 58.40 per 10 000 population. Many developing countries experience structural vulnerabilities and loss of HRH, such as Nigeria.[57 58] Challenges in national development priorities often divert scarce resources from the health sector.[47-50 57 58] Zimbabwe was the only country with negative HRH growth, multiple inflationary financial crises, and an unstable regime, and its deployment decisions on healthcare were elusive, even during the apparent losses to the health workforce. Although this inequality in health workforce exists, the gap has been narrowing since the turn of the century, which may be due in part to the effective implementation of both millennium development goals and sustainable development goals.[4-6]

Changes in all cause and cause specific mortality

In the current study, the large differences in mortality among countries might be related to inequalities in HRH, economic development, social security, medical insurance system, lifestyle, and dietary habits.[59-66] Compared with the Solomon Islands, some countries, such as Ethiopia and Palestine, had a very low HRH density in 2019 but all cause mortality was not high. Ethiopia is the second most populous country in Africa, and it has the fastest growing African economy in recent decades.[67] Life expectancy in Ethiopia increased from 52 years in 2000 to 66 years in 2019, and the rate of infant mortality reduced by more than 50%.[68] Most of the health related millennium development goals have been achieved in Ethiopia and are considered to be attributed to a comprehensive approach to health development, including health financing and other socioeconomic systems.[69 70] Palestine is a refugee area that has received high levels of aid and a considerable amount of charitable resources per capita.[71] Even the poorest countries seem to have achieved important reductions in all cause mortality by implementing these multi-tiered strategies.[70]

In addition, mortality rates for several diseases in our study were increasing, the most notable being for mental disorders, which had the highest estimated annual percentage change at 1.6%, although the mortality rate was still low at 0.001 per 100 000 population. Psychological problems are becoming more common as a result of heightened social pressures, and diagnostic capabilities have improved with advances in neuroscience and psychiatric care.[72-74] The mortality rate for HIV/AIDS and sexually transmitted infections increased from 2.0 to 3.4 per 100 000 population between 1990 and 2019; however, since 2010 the number of patients with newly diagnosed HIV has decreased by 32% (mostly among children, −52%), and AIDS related deaths have decreased by 68%, after peaking at two million in 2004, as a result of global initiatives to combat it over the past decades.[75-79] Nonetheless, the challenge to control sexually transmitted infections is big.[80] The estimated annual percentage change in mortality rate due to diabetes and kidney disease was 0.2%, in line with the findings of a previous study.[81] Another study indicated that the global burden of diabetes has increased statistically significantly since 1990, and that it continues to rise.[82] For skin and subcutaneous diseases (estimated annual percentage change 0.6%), many factors could explain the prevalence of skin diseases, including local weather, climate change, and diet. Differences might also be related to changes in dermatologist density and health insurance coverage.[83] The burden of musculoskeletal disorders may be underestimated, particularly because of population growth, ageing, and other associated risk factors (eg, obesity, injuries, and sedentary lifestyles).[84 85]

HRH and mortality

The negative association between total HRH density and mortality rates was statistically significant and more pronounced for some types of cause specific mortality. Neoplasms, mental disorders, substance use disorders, musculoskeletal disorders, self-harm, and interpersonal violence were, however, found to be positively related to total HRH density. Previous studies and statements of the World Cancer Research Fund International claimed that the age standardized mortality rate of neoplasms appeared to be higher in more developed countries, because of ageing and inappropriate lifestyle behaviors.[86-88] These risk factors are also becoming prevalent in low to middle income countries.[86] Mental disorders and their detection are of greater concern in more developed countries with high HRH density. The relative risk of all violent outcomes typically increased twofold to fourfold in most patients with a diagnosis of mental disorders compared with those without, potentially explaining the association between self-harm and interpersonal violence mortality and HRH density.[89] The higher mortality of substance use disorders in countries with a high HRH density was attributed to high rates of illicit drug use in high income countries.[90] Substance use disorders are also associated with an increased risk of death by suicide.[91] Most painful musculoskeletal disorders worsen with age, and most are related to multiple non-communicable diseases associated with musculoskeletal pain. The increasing incidence of reduced physical activity, non-communicable diseases, and age related diseases may explain the higher mortality rate for musculoskeletal disorders in countries with a high HRH density.[85]

The anomalous association between total HRH density and mortality from HIV/AIDS and sexually transmitted infections appeared challenging to elucidate, so we disaggregated the HRH density into 16 cadres to refine our results. Shortages of doctors, dentistry staff, and pharmaceutical staff were more likely to be associated with higher mortality (see supplementary figures S3, S5, and S6). The presence of oral lesions is regarded as an important sign in the diagnosis of AIDS.[92 93] More than one third of people with AIDS have oral lesions, and the average prevalence is higher in developing countries.[93] Therefore, well trained dentistry staff can serve as sentinels in the detection and early diagnosis of AIDS.[92 93] As key members of the treatment team, pharmacists often jointly develop treatment plans with doctors and counsel infected patients on drugs, to improve adherence to treatment.[94] The appropriate use of drugs for HIV pre-exposure prophylaxis and postexposure prophylaxes is also key to reducing infection and mortality rates.[95 96] Apart from the previously mentioned factors associated with HIV diagnosis and treatment, many social problems, policies, laws, ethics, and other factors about the HIV/AIDS epidemic affect health outcomes and are more likely to produce abnormal results of primary analysis. Under the premise of ensuring a strong development of HRH, we suggest that countries should widely promote social mobilization, especially in high prevalence and high mortality areas, and that effective measures should be broadly rolled out (see supplementary materials section 3.3.2 for literature review).

In addition, we also discovered the association between 16 HRH cadres and 20 other types of cause specific mortality, suggesting the importance of some HRH categories may have been underappreciated in the past. For instance, periodontitis seems to be associated with an increased risk of diabetes, due to infection or inflammatory responses, or both, whereas the periodontal treatment delivered by dentistry may lead to an improvement in glycemic control in people with type 2 diabetes.[97 98] Mental health comorbidities of diabetes can affect adherence to treatment, thereby increasing the risk of serious complications, which may then lead to premature death.[99] Optometrists are often the first to notice symptoms or signs of diabetes and other kidney disease by looking for changes in blood vessels in the eye, and thereby helping to improve diabetes outcomes.[100-102] Overall, the density of dentistry staff, psychologists, and optometrists warrants more attention in relation to deaths from diabetes and kidney diseases (see supplementary materials section 3.3 for other associations).

Time to strengthen the development of HRH

The governments of some countries affected by famine, ware, and pollution lack resources to deal with the shortage of HRH.[103-106] The covid-19 pandemic imposes additional burdens, particularly on HRH and deaths.[57] The growing scarcity of HRH in low to middle income countries makes it challenging to put HRH development on hold. The High-Level Commission on Health Employment and Economic Growth highlights that targeted investments in HRH contribute to economic growth.[107] The Brazilian government promoted the expansion of numbers of primary care doctors, and established new medical schools in 2013,[108] and the modest reduction in mortality was associated with the introduction of the programme.[108] Countries may need to share responsibilities (shared financing models); actively develop sustainable and mutually beneficial partnerships; respond to the human resource crisis through decentralization, central management coordination, and stakeholder participation in policy decision coordination processes; and expand fiscal space to fund health sector positions while investing in health worker education.[109 110]

Strengths and limitations of this study

Our findings highlight the importance of expanding the financing of health and developing equity oriented policies for the health workforce to reduce deaths related to an inadequate HRH. The demands for HRH vary from country to country because of the inherent inequities and constant changes in disease spectrums.[111] However, our study has several potential limitations. First, the quality and quantity of Global Burden of disease data chiefly depended on the validity and reliability of predictive models when data for certain years or locations were not available.[112] Therefore, when specific data were applied to countries and territories with underdeveloped medical systems, the findings needed to be interpreted with caution.[81] Second, some environmental data were utilized in the Global Burden of Disease estimation of mortality, but the means to measure these factors in low to middle income countries was limited. The lack of such data could lead to some underestimation of mortality in low to middle income countries.[113] Third, considering that most of the 32 excluded countries were at low development level, our findings might have underestimated the association between HRH density and mortality since we discovered a greater mortality effect in those countries ranked lower on the human development index. Nevertheless, our study has important implications for highlighting the positive health effects of HRH. We suggest that more countries and territories should establish high quality databases such as vital registration to help towards more comprehensive and rigorous research.

Conclusions

Although inequalities in HRH have been decreasing globally over the past 30 years but persist. All cause mortality and most types of cause specific mortality were relatively higher in countries and territories with a limited health workforce, especially for several specific HRH cadres among priority diseases, such as HIV/AIDS and sexually transmitted infections, maternal and neonatal disorders, diabetes and kidney diseases. Our findings reinforce the importance of political commitment being strengthened to develop equity oriented policies for health workforces by expanding the financing of health and implementing targeted interventions to reduce deaths as a result of inadequate HRH to achieve the timely goal of universal health coverage by 2030.

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Data sharing: All data in the study are available at https://ghdx.healthdata.org/gbd-2019, http://data.un.org/, https://ourworldindata.org/. The analytic codes of this study are available on GitHub at https://github.com/cheng01zi/codes-for-inequalities-in-HRH.git.

The lead author (JL) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Dissemination to participants and related patient and public communities: Dissemination of the results to all cadres of human resources of health, experts in the specialty of healthcare, and policy makers will be undertaken through the Global Scientific Data Platform for Prevention, Control and Management of Major Infectious Diseases at https://www.globalbigmid.com. Researchers involved in the study will disseminate the results to related officials and the public through professional bodies' websites and conferences at the national level.

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Supplementary information: Additional methods, results, discussion, figures, and tables