Healthcare Access and Quality Index based on mortality from causes amenable to personal health care in 195 countries and territories, 1990–2015: a novel analysis from the Global Burden of Disease Study 2015

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Summary

Background National levels of personal health-care access and quality can be approximated by measuring mortality rates from causes that should not be fatal in the presence of effective medical care (ie, amenable mortality). Previous analyses of mortality amenable to health care only focused on high-income countries and faced several methodological challenges. In the present analysis, we use the highly standardised cause of death and risk factor estimates generated through the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) to improve and expand the quantification of personal health-care access and quality for 195 countries and territories from 1990 to 2015.

Methods We mapped the most widely used list of causes amenable to personal health care developed by Nolte and McKee to 32 GBD causes. We accounted for variations in cause of death certification and misclassifications through the extensive data standardisation processes and redistribution algorithms developed for GBD. To isolate the effects of personal health-care access and quality, we risk-standardised cause-specific mortality rates for each geography-year by removing the joint effects of local environmental and behavioural risks, and adding back the global levels of risk exposure as estimated for GBD 2015. We employed principal component analysis to create a single, interpretable summary measure–the Healthcare Quality and Access (HAQ) Index–on a scale of 0 to 100. The HAQ Index showed strong convergence validity as compared with other health-system indicators, including health expenditure per capita (r=0·88), an index of 11 universal health coverage interventions (r=0·83), and human resources for health per 1000 (r=0·77). We used free disposal hull analysis with bootstrapping to produce a frontier based on the relationship between the HAQ Index and the Socio-demographic Index (SDI), a measure of overall development consisting of income per capita, average years of education, and total fertility rates. This frontier allowed us to better quantify the maximum levels of personal health-care access and quality achieved across the development spectrum, and pinpoint geographies where gaps between observed and potential levels have narrowed or widened over time.

Findings Between 1990 and 2015, nearly all countries and territories saw their HAQ Index values improve; nonetheless, the difference between the highest and lowest observed HAQ Index was larger in 2015 than in 1990, ranging from 28·6 to 94·6. Of 195 geographies, 167 had statistically significant increases in HAQ Index levels since 1990, with South Korea, Turkey, Peru, China, and the Maldives recording among the largest gains by 2015. Performance on the HAQ Index and individual causes showed distinct patterns by region and level of development, yet substantial heterogeneities emerged for several causes, including cancers in highest-SDI countries; chronic kidney disease, diabetes, diarrhoeal diseases, and lower respiratory infections among middle-SDI countries; and measles and tetanus among lowest-SDI countries. While the global HAQ Index average rose from 40·7 (95% uncertainty interval, 39·0–42·8) in 1990 to 53·7 (52·2–55·4) in 2015, far less progress occurred in narrowing the gap between observed HAQ Index values and maximum levels achieved; at the global level, the difference between the observed and frontier HAQ Index only decreased from 21·2 in 1990 to 20·1 in 2015. If every country and territory had achieved the highest observed HAQ Index by their corresponding level of SDI, the global average would have been 73·8 in 2015. Several countries, particularly in eastern and western sub-Saharan Africa, reached HAQ Index values similar to or beyond their development levels, whereas others, namely in southern sub-Saharan Africa, the Middle East, and south Asia, lagged behind what geographies of similar development attained between 1990 and 2015.

Interpretation This novel extension of the GBD Study shows the untapped potential for personal health-care access and quality improvement across the development spectrum. Amid substantive advances in personal health care at the national level, heterogeneous patterns for individual causes in given countries or territories suggest that few places have consistently achieved optimal health-care access and quality across health-system functions and therapeutic areas. This is especially evident in middle-SDI countries, many of which have recently undergone or are currently experiencing epidemiological transitions. The HAQ Index, if paired with other measures of health-system

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characteristics such as intervention coverage, could provide a robust avenue for tracking progress on universal health coverage and identifying local priorities for strengthening personal health-care quality and access throughout the world.

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Introduction

Quantifying how much personal health care can improve population health and ultimately health-system performance is a crucial undertaking, particularly following the inclusion of universal health coverage (UHC) in the Sustainable Development Goals (SDGs).[1] Mortality from causes considered amenable to personal health care serve as an important proxy of health-care access and quality (panel),[4,6–8] and thus can be used to benchmark dimensions of health-system performance and to identify untapped potential for advancing personal health-care access and quality.[9–12] Much debate exists concerning the relative contributions of personal health care, population-level health initiatives, and social determinants to population health.[13–16] Studies show that access to high-quality health care substantially improves many health outcomes, including infectious diseases (eg, tuberculosis and measles);[17–19] maternal and neonatal disorders;[20,21]

Research in context

Evidence before this study

In the last several decades, various studies have used measures of amenable mortality, or deaths that could be avoided in the presence of high-quality personal health care, to garner signals about health-system delivery, effectiveness, and performance. Rutstein and colleagues developed an initial list of conditions from which death was "unnecessary and untimely" during the late 1970s, while Charlton and colleagues were the first to apply this concept to population-level analyses in England and Wales. Although variations of amenable cause lists exist today, the most widely used cause list of 33 conditions was developed and further honed by Nolte and McKee during the early-to-mid 2000s. Such analyses of health-care access and quality, as approximated by amenable mortality, have been limited to Europe, Organisation for Economic Co-operation and Development (OECD) countries, and country-specific assessments, including the USA, Australia, and New Zealand. These studies acknowledge several methodological challenges that may impede the policy utility and applications of their results. Heterogeneity in cause of death certification and misclassification, even for countries with complete vital registration systems, can hinder comparability of results over time and place. Further, researchers commonly acknowledge that variations in measured amenable mortality rates may be more reflective of differences in underlying risk factor exposure rather than true differences in personal health-care access and quality.

Added value of this study

The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) provides an appropriate analytic framework through which these main challenges in approximating personal health-care access and quality can be addressed. First, the extensive cause of death data processing and standardisation that occur within GBD allow for the systematic identification and redress of cause of death certification errors or misclassification. These adjustments are conducted across all geographies and over time, accounting for known misclassification patterns and applying well established redistribution algorithms for causes designated to so-called garbage codes, or causes of death that could not or should not be classified as underlying causes of death. Second, we draw on GBD's comparative risk assessment analyses to risk-standardise national cause-specific mortality rates to global levels of risk exposure; this step helps to remove variations in death rates due to risk exposure rather than differences in personal health-care access and quality. Third, we construct the Healthcare Access and Quality (HAQ) Index based on risk-standardised cause-specific death rates to facilitate comparisons over time and by geography. Finally, we produced a HAQ Index frontier to enable a better understanding of the maximum observed levels of the HAQ Index across the development spectrum, and what untapped potential for improving personal health-care access and quality may exist given a country or territory's current resources.

Implications of all the available evidence

Our results point to substantive gains for advancing personal health-care access and quality throughout the world since 1990. However, the gap between places with the highest and lowest HAQ Index in 1990 increased by 2015, suggesting that geographic inequalities in personal health-care access and quality might be on the rise. In 2015, countries in western Europe generally had the highest HAQ Index values while geographies in sub-Saharan Africa and Oceania mainly saw the lowest, further emphasising these disparities. A number of countries achieved improvements in the HAQ Index that exceeded the average found for their development level, identifying possible success stories in markedly advancing personal health-care access and quality at the national level. Based on our frontier analysis, many countries and territories currently experience untapped potential for improving health-care access and quality, on the basis of their development, a finding that could be transformative for prioritising particular health-sector reforms, pinpointing cause-specific therapeutic areas that require more policy attention, and monitoring overall progress toward universal health coverage.

several cancers (eg, testicular, skin, and cervical cancers);[22,23] and many non-communicable diseases (NCDs) such as cerebrovascular disease (stroke),[24] diabetes,[25] and chronic kidney disease.[26] Consequently, assessing mortality rates from these conditions, which are considered amenable to personal health care,[4,6–8] can provide vital insights into access to and quality of health care worldwide. Assessments of both mortality and disease burden attributable to risk factors modifiable through public health programmes and policy (eg, tobacco taxation), combined with access to high-quality personal health care, can provide a more complete picture of the potential avenues for health improvement.

In the late 1970s, Rutstein and colleagues first introduced the idea of "unnecessary, untimely deaths", proposing a list of causes from which death should not occur with timely and effective medical care.[6] Eventually termed "amenable mortality", this approach has been modified and extended since, with researchers refining the list of included conditions by accounting for advances in medical care, the introduction of new interventions, and improved knowledge of cause-specific epidemiology.[7,8,27–29] Numerous studies have subsequently assessed amenable mortality trends over time, by sex, and across ages in different populations;[2,10,11,30–33] examples include analyses showing variations in amenable mortality within the European Union and Organisation for Economic Co-operation and Development (OECD),[3,34] and how much the US health system has lagged behind other higher-income countries.[30,31] Some studies also extended the set of amenable conditions to include those targeted by public health programmes.[31] The most widely cited and utilised list of causes amenable to personal health care is that of Nolte and McKee,[4] which has been extensively used in Europe, the USA, and other OECD countries.[9,11,30,31,35]

Previously, several technical challenges have emerged concerning the quantification of mortality from conditions amenable to personal health care and its use for understanding overall health-care access and quality. First, discrepancies in cause of death certification practices and misclassification over time and across geographies affect comparisons of amenable mortality.[4,36] Second, observed geographic and temporal variations in deaths from selected amenable causes (eg, stroke and heart disease) might be attributed partly differences in risk factor exposure (eg, diet, high BMI, and physical activity) rather than actual differences in access to quality personal health care. Public health programmes and policies might modify these risks in well-functioning health systems, but risk variation can still confound the measurement of personal health-care access and quality. Third, much of this work has occurred in higher-income settings, with few studies applying the concept of amenable mortality as a mechanism for assessing access and quality to personal health care in lower-resource settings. Other critiques involve weak correlations between observed trends and variations in amenable mortality and indicators of health-care provision and spending, although this result could

Panel: Context and definitions

With the present analysis, we use the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) to approximate average levels of personal health-care access and quality for 195 countries and territories from 1990 to 2015. Here we define key concepts frequently used in the literature focused on assessing health-care quality and how they relate to GBD terminology:

Avertable burden refers to disease burden that could be avoided in the presence of high-quality personal health care in addition to disease burden that could be prevented through effective public health (ie, non-personal) interventions.

Amenable burden entails disease burden that could be avoided in the presence of high-quality personal health care.[2,3] To be considered a cause amenable to personal health care, effective interventions must exist for the disease.[4] The most widely used and cited list of causes amenable to health care is that of Nolte and McKee.

Preventable burden involves disease burden that could be avoided through public health programmes or policies focused on wider determinants of health, such as behavioural and lifestyle influences, environmental factors, and socioeconomic status.[2,3] For some causes, both personal health care and public health programmes and policies can reduce burden.

Within the GBD framework, we have two related terms: attributable and avoidable burden.[5]

Attributable burden refers to the difference in disease burden observed at present and burden that would have been observed in a population if past exposure was at the lowest level of risk.

Avoidable burden concerns the reduction in future disease burden if observed levels of risk factor exposure today were decreased to a counterfactual level.

For this study, we use the definition of amenable burden and focus on amenable mortality to provide a signal on approximate average levels of national personal health-care access and quality. Future analyses facilitated through the GBD study aim to provide more comprehensive assessments of health systems using amenable burden and preventable burden.

Garbage codes refer to causes certified by physicians on death certificates that cannot or should not be considered the actual underlying causes of death. Examples include risk factors like hypertension, non-fatal conditions like yellow nails, and causes that are on the final steps of a disease pathway (eg, certifying cardiopulmonary arrest as the cause when ischaemic heart disease is the true underlying cause of death). A vital strength of the GBD Study is its careful identification of garbage codes by cause, over time, and across locations, and subsequent redistribution to underlying causes based on the GBD cause list.

Risk-standardisation involves removing the joint effects of environmental and behavioural risk exposure on cause-specific mortality rates at the country or territory level for each year of analysis, and then adding back the global average of environmental and behavioural risk exposure for every geography-year. The goal of risk-standardisation is to eliminate geographic or temporal differences in cause-specific mortality due to variations in risk factors that are not immediately targeted by personal health care—and thus provide comparable measures of outcomes amenable to personal health-care access and quality over place and time.

Frontier analysis refers to the approach used for ascertaining the highest achieved values on the Healthcare Access and Quality Index (HAQ Index) on the basis of development status, as measured by the Socio-demographic Index (SDI). The HAQ Index frontier delineates the maximum HAQ Index reached by a location as it relates to SDI; if a country or territory falls well below the frontier value given its level SDI, this finding suggests that greater gains in personal health-care access and quality should be possible based on the country or territory's place on the development spectrum.

	Amenable age range (years)
Communicable, maternal, neonatal, and nutritional diseases	
Tuberculosis	0–74
Diarrhoea, lower respiratory, and other common infectious diseases	
Diarrhoeal diseases	0–14
Lower respiratory infections	0–74
Upper respiratory infections	0–74
Diphtheria	0–74
Whooping cough	0–14
Tetanus	0–74
Measles	1–14
Maternal disorders	0–74
Neonatal disorders	0–74
Non-communicable diseases	
Neoplasms	
Colon and rectum cancer	0–74
Non-melanoma skin cancer (squamous-cell carcinoma)	0–74
Breast cancer	0–74
Cervical cancer	0–74
Uterine cancer	0–44
Testicular cancer	0–74
Hodgkin's lymphoma	0–74
Leukaemia	0–44
Cardiovascular diseases	
Rheumatic heart disease	0–74
Ischaemic heart disease	0–74
Cerebrovascular disease	0–74
Hypertensive heart disease	0–74
Chronic respiratory diseases	1–14
Digestive diseases	
Peptic ulcer disease	0–74
Appendicitis	0–74
Inguinal, femoral, and abdominal hernia	0–74
Gallbladder and biliary diseases	0–74
Neurological disorders	
Epilepsy	0–74
Diabetes, urogenital, blood, and endocrine diseases	
Diabetes mellitus	0–49
Chronic kidney disease	0–74
Other non-communicable diseases	
Congenital heart anomalies	0–74
Injuries	
Unintentional injuries	
Adverse effects of medical treatment	0–74

The age groups for which mortality is regarded as amenable to health care are listed. Causes are ordered on the basis of the GBD cause list and corresponding cause group hierarchies. GBD=Global Burden of Disease.

Table 1: **Causes for which mortality is amenable to health care mapped to GBD 2015 causes**

occur if health-care quality is heterogeneous within countries.[37–40] Additionally, existing lists might exclude causes for which health care can avert death, such as the effects of trauma care on various injuries,[4,41,42] and the ages at which personal health care can reduce mortality, namely beyond the age of 75.[43,44]

The goal of this analysis is to use estimates of mortality amenable to personal health care from the Global Burden of Diseases, Injuries, and Risk Factors Study 2015 (GBD 2015) to approximate access to and quality of personal health care in 195 countries and territories from 1990 to 2015. Quantifying access to and quality of personal health care has many policy uses, and no consistent measures of personal health-care access and quality currently list across the development spectrum; for instance, the World Bank coverage index only includes three interventions,[45] and the 2010–11 International Labour Organization's indicator of formal health coverage covered 93 countries, with substantial data missingness for sub-Saharan Africa.[46] The highly standardised cause of death estimates generated through GBD,[47] along with risk factor exposure,[48] can address several limitations associated with previous studies of amenable mortality. GBD provides comprehensive, comparable estimates of cause-specific death rates by geography, year, age, and sex through its extensive data correction processes to account for variations in cause of death certification.[47] The quantification of risk exposure and risk-attributable deaths due to 79 risk factors through GBD allows us to account for variations in risk exposure across geographies and time,[48] and thus helps to isolate variations in death rates due to personal health-care access and quality. We also examine the relationship between our measure of health-care access and quality, as defined by risk-standardised mortality rates amenable to health care, across development levels, as reflected by the Socio-demographic Index (SDI). Finally, we produce a frontier of maximum levels of personal health-care access and quality observed on the basis of SDI, which allows us to quantify the potential for further improvement in relation to development status.

Methods

Overview

We employed the most widely cited and used framework for assessing mortality amenable to personal health care.[4,9,11,30,31,35] The Nolte and McKee cause list does not include all possible causes for which health care can improve survival; however, it does provide a set of conditions for which there is a reasonable consensus that personal health care has a major effect (table 1). Starting with this list, our analysis followed four steps: mapping the Nolte and McKee cause list to GBD causes; risk-standardising mortality rates to remove variations in death rates not easily addressed through personal health care; computing a summary measure of personal health-care access and quality using principal component analysis (PCA); and assessing the highest recorded levels of health-care access and quality across the development spectrum.

This study draws from GBD 2015 results; further detail on GBD 2015 data and methods are available

	Source and year	Geographies represented	HAQ Index construction			
			PCA weighted	EFA weighted	Geometric mean	Mean
Health expenditure per capita	GBD 2015	195	0·884	0·880	0·854	0·864
Hospital beds (per 1000)	GBD 2015	195	0·700	0·683	0·625	0·650
UHC tracer index of 11 interventions	GBD 2015	188	0·826	0·820	0·812	0·818
Physicians, nurses, and midwives per 1000	WHO 2010	73	0·769	0·755	0·725	0·732
Proportion of population with formal health coverage	ILO 2010–11	93	0·808	0·798	0·773	0·781
Coverage index of three primary health-care interventions	World Bank 2015	123	0·601	0·589	0·557	0·570

The universal health coverage tracer index of 11 interventions included coverage of four childhood vaccinations (BCG, measles, three doses of diphtheria-pertussis-tetanus, and three doses of polio vaccines); skilled birth attendance; coverage of at least one and four antenatal care visits; met need for family planning with modern contraception; tuberculosis case detection rates; insecticide-treated net coverage; and antiretroviral therapy coverage for populations living with HIV. The World Bank coverage index included coverage of three interventions: three doses of diphtheria-pertussis-tetanus vaccine; at least four antenatal care visits; and children with diarrhoea receiving appropriate treatment. HAQ Index=Healthcare Access and Quality Index. PCA=principal components analysis. EFA=exploratory factor analysis. GBD=Global Burden of Disease. UHC=universal health coverage. ILO=International Labour Organization.

Table 2: **Correlations between different constructions of the HAQ Index and existing indicators of health-care access or quality**

elsewhere.[47–50] For the present analysis, a vital strength of GBD is its careful evaluation and correction of cause of death certification problems and misclassification at the national level. In the GBD, we systematically identified causes of death that could not or should not be underlying causes of death (so-called garbage codes), and applied established statistical algorithms to correct for and redistribute these deaths.[51]

Our study complies with the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER);[52] additional information on the data and modelling strategies used can be found in the appendix.

Mapping the Nolte and McKee amenable cause list to the GBD cause list

Drawing from Nolte and McKee's list of 33 causes amenable to personal health care,[4,9,11,30,31,35] we mapped these conditions to the GBD cause list based on corresponding International Classification of Diseases (ICD) codes (appendix p 18). In GBD, thyroid diseases and benign prostatic hyperplasia are part of a larger residual category and thus were excluded. Diphtheria and tetanus are separate causes in GBD so we reported them individually. Because of its extensive processes used to consistently map and properly classify ICD causes over time,[47,53] GBD supported the assessment of 32 causes on the Nolte and McKee cause list from 1990 to 2015.

Age-standardised risk-standardised death rates

Some variation in death rates for amenable causes are due to differences in behavioural and environmental risk exposure rather than differences in personal health-care access and quality.[48,54,55] Using the wide range of risk factors assessed by GBD,[48] we risk-standardised death rates to the global level of risk exposure.[48] We did not risk-standardise for variations in metabolic risk factors directly targeted by personal health care: systolic blood pressure, total cholesterol, and fasting plasma glucose. For example, stroke deaths due to high systolic blood pressure are amenable to primary care management of hypertension.

To risk-standardise death rates, we removed the joint effects of national behavioural and environmental risk levels calculated in GBD, and added back the global levels of risk exposure:

$$\mathrm{mr}_{jascy} = \mathrm{m}_{jascy}\left(\frac{1-JPAF_{jascy}}{1-JPAF_{jasgy}}\right)$$

where m_{jascy} is the death rate from cause j in age a, sex s, location c, and year y; mr_{jascy} is the risk-standardised death rate; $JPAF_{jascy}$ is the joint population attributable fraction (PAF) for cause j, in age a, sex s, country c, and year y for all behavioural and environmental risks included in GBD; and $JPAF_{jasgy}$ is the joint PAF for cause j, in age a, sex s, and year y at the global level.

See Online for appendix

GBD provides joint PAF estimation for multiple risks combined, which takes into account the mediation of different risks through each other. Further detail on joint PAF computation is available in the appendix (pp 5–8).

We used the GBD world population standard to calculate age-standardised risk-standardised death rates from each cause regarded as amenable to health care.[47] We did not risk-standardise death rates from diarrhoeal diseases as mortality attributable to unsafe water and sanitation was not computed for high-SDI locations; such standardisation could lead to higher risk-standardised death rates in those countries compared with countries where mortality was attributed to unsafe water and sanitation.[48] With all causes for which no PAFs are estimated in GBD, such as neonatal disorders and testicular cancer, risk-standardised death rates equalled observed death rates.

The effects of risk-standardisation are highlighted by comparing the log of age-standardised mortality rates to

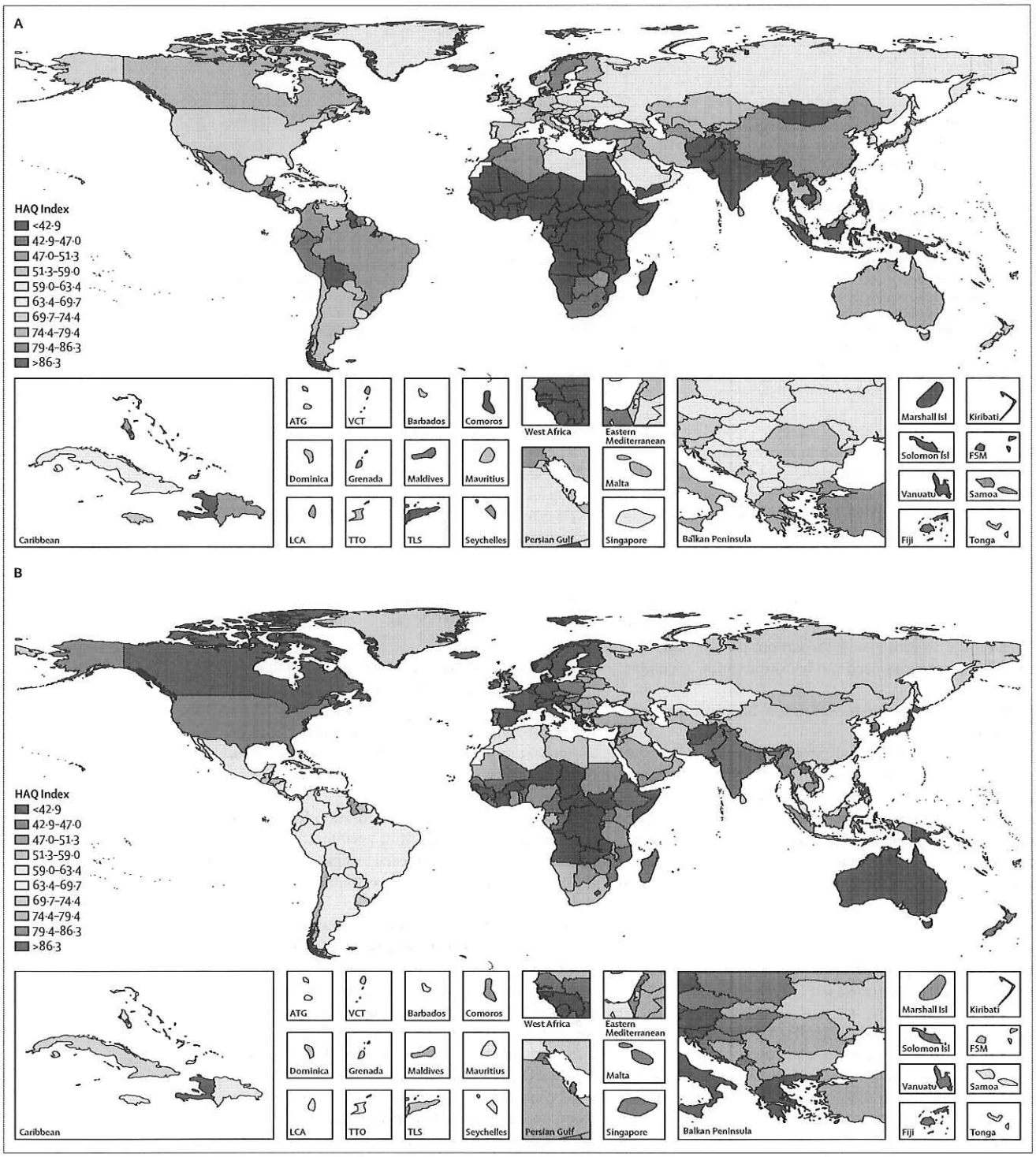


Figure 1: **Map of HAQ Index values, by decile, in 1990 (A) and 2015 (B)**
Deciles were based on the distribution of HAQ Index values in 2015 and then were applied for 1990. HAQ Index = Healthcare Access and Quality Index. ATG=Antigua and Barbuda. VCT=Saint Vincent and the Grenadines. LCA=Saint Lucia. TTO=Trinidad and Tobago. TLS=Timor-Leste. FSM=Federated States of Micronesia.

the log of age-standardised risk-standardised mortality rates for amenable causes (appendix p 14). For each SDI quintile, many countries had differing levels of age-standardised mortality rates but their risk-standardised mortality rates were similar, demonstrating how underlying local risk exposure can skew measures of mortality amenable to personal health care.

Construction of the Healthcare Access and Quality Index based on age-standardised risk standardised death rates

To construct the Healthcare Access and Quality (HAQ) Index, we first rescaled the log age-standardised risk-standardised death rate by cause to a scale of 0 to 100 such that the highest observed value from 1990 to 2015 was 0 and the lowest was 100. To avoid the effects of fluctuating death rates in small populations on rescaling, we excluded populations less than 1 million population from setting minimum and maximum values. Any location with a cause-specific death rate below the minimum or above the maximum from 1990 to 2015 was set to 100 or 0, respectively.

Because each included cause provided some signal on average levels of personal health-care access and quality, we explored four approaches to construct the HAQ Index: PCA, exploratory factor analysis, arithmetic mean, and geometric mean. Details on these four approaches are in the appendix (pp 7, 8, 21, 22). All four measures were highly correlated, with Spearman's rank order correlations exceeding r_s=0·98. We selected the PCA-derived HAQ Index because it provided the strongest correlations with six other currently available cross-country measures of access to care or health-system inputs (table 2). Three indicators came from the GBD Study 2015: health expenditure per capita, hospital beds per 1000, and the UHC tracer intervention index, a composite measure of 11 UHC tracer interventions (four childhood vaccinations; skilled birth attendance; coverage of at least one and four antenatal care visits; met need for family planning with modern contraception; tuberculosis case detection rates; insecticide-treated net coverage; and antiretroviral therapy coverage for populations living with HIV).[56] Three indicators came from WHO (physicians, nurses, and midwives per 1000),[57] the International Labour Organization,[46] and the World Bank (coverage index based on diphtheria-pertussis-tetanus vaccine coverage, coverage of at least four antenatal care visits, and proportion of children with diarrhoea receiving appropriate treatment).[45] All indicators had correlation coefficients greater than 0·60, and three exceeded 0·80 (health expenditure per capita, the UHC tracer index, and International Labour Organization formal health coverage).

The appendix (pp 21, 22) provides final rescaled PCA weights derived from the first five components that collectively accounted for more than 80% of the variance in cause-specific measures. Colon and breast cancer had negative PCA weights, which implied higher death rates were associated with better access and quality of care; because this cannot be true we set these weights to zero in the final PCA-derived HAQ Index. The appendix (p 15) compares each geography's HAQ Index in 2015 with the log of its age-standardised risk-standardised mortality rates.

Quantifying maximum levels of the HAQ Index across the development spectrum

To better understand maximum levels of personal health-care access and quality potentially achievable across the development spectrum, we produced a frontier based on the relationship between the HAQ Index and SDI. We tested both stochastic frontier analysis models and data envelopment analysis; however, the relationship between SDI and the HAQ Index did not fit standard stochastic frontier analysis models,[58] and data envelopment analysis cannot account for measurement error and is sensitive to outliers.[59] To generate a frontier fit that closely follows the observed HAQ Index and allowed for measurement error, we used free disposal hull analysis on 1000 bootstrapped samples of the data.[58] Every bootstrap included a subset of locations produced by randomly sampling (with replacement) from all GBD geographies. The final HAQ Index value was drawn from the uncertainty distribution for each location-year, with outliers removed by excluding super-efficient units; additional methodological detail can be found in the appendix (pp 9–12). Last, we used a Loess regression to produce a smooth frontier for each five-year interval from 1990 to 2015. For every geography, we report the maximum possible HAQ Index value on the basis of SDI in 1990 and 2015, while values for all years can be found in the appendix (pp 23–28).

Uncertainty analysis

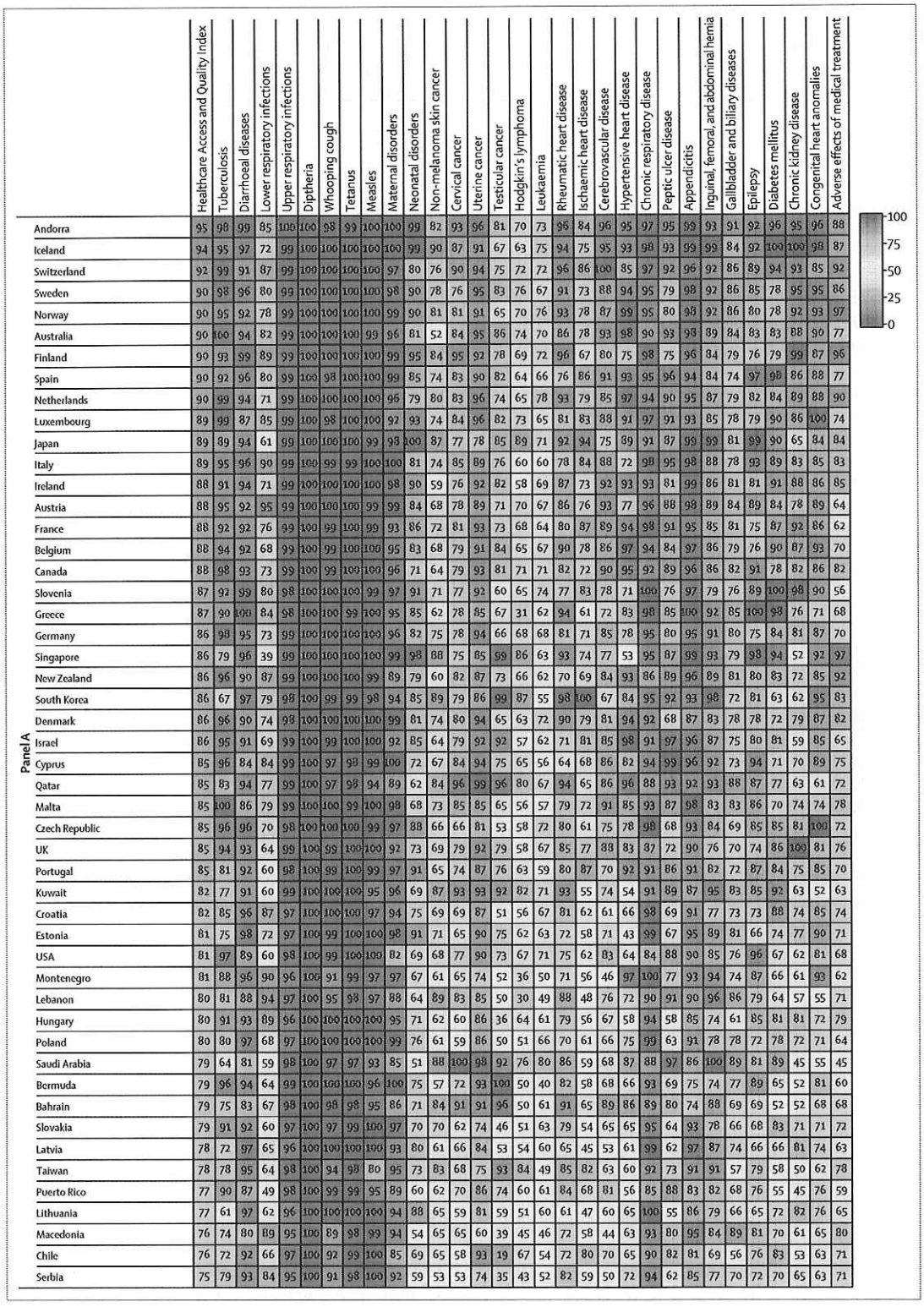
GBD aims to propagate all sources of uncertainty through its estimation process,[47,48] which results in uncertainty intervals (UIs) accompanying each point estimate of death by cause, geography, year, age group, and sex. We computed the HAQ Index for each geography-year based on 1000 draws from the posterior distribution for each included cause of death. We report 95% UIs based on the ordinal 25th and 975th draws for each quantity of interest.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Distinct geographic patterns emerged for overall HAQ Index levels and gains from 1990 to 2015 (figure 1). Andorra and Iceland had the highest HAQ Index in 1990, whereas most of sub-Saharan Africa and south Asia and



Panel A

	Healthcare Access and Quality Index	Tuberculosis	Diarrhoeal diseases	Lower respiratory infections	Upper respiratory infections	Diptheria	Whooping cough	Tetanus	Measles	Maternal disorders	Neonatal disorders	Non-melanoma skin cancer	Cervical cancer	Uterine cancer	Testicular cancer	Hodgkin's lymphoma	Leukaemia	Rheumatic heart disease	Ischaemic heart disease	Cerebrovascular disease	Hypertensive heart disease	Chronic respiratory disease	Peptic ulcer disease	Appendicitis	Inguinal, femoral, and abdominal hernia	Gallbladder and biliary diseases	Epilepsy	Diabetes mellitus	Chronic kidney disease	Congenital heart anomalies	Adverse effects of medical treatment
Andorra	95	98	99	85	100	100	98	99	100	100	99	82	93	96	81	70	73	96	84	96	95	97	95	99	93	91	92	96	95	96	88
Iceland	94	95	97	72	99	100	100	100	100	100	99	90	87	91	67	63	75	94	75	95	93	98	93	99	99	84	92	100	100	98	87
Switzerland	92	99	91	87	99	100	100	100	100	97	80	76	90	94	75	72	72	96	86	100	85	97	92	96	92	86	89	94	93	85	92
Sweden	90	98	96	80	99	100	100	100	100	98	90	78	76	95	83	76	67	91	73	88	94	95	79	98	92	86	85	78	95	95	86
Norway	90	95	92	78	99	100	100	100	100	99	90	81	81	91	65	70	76	93	78	87	99	95	80	98	92	86	80	78	92	93	97
Australia	90	100	94	82	99	100	100	100	99	96	81	52	84	95	86	74	70	86	78	93	98	90	93	98	89	84	83	83	88	90	77
Finland	90	93	99	89	99	100	100	100	100	99	95	84	95	92	78	69	72	96	67	80	75	98	75	96	84	79	76	79	99	87	96
Spain	90	92	96	80	99	100	98	100	100	99	85	74	83	90	82	64	66	76	86	91	93	95	96	94	84	74	97	98	86	88	77
Netherlands	90	99	94	71	99	100	100	100	100	96	79	80	83	96	74	65	78	93	79	85	97	94	90	95	87	79	82	84	89	88	90
Luxembourg	89	99	87	85	99	100	98	100	100	92	93	74	84	96	82	73	65	81	83	88	91	97	91	93	85	78	79	90	86	100	74
Japan	89	89	94	61	99	100	100	100	99	98	100	87	77	78	85	89	71	92	94	75	89	91	87	99	99	81	99	90	65	84	84
Italy	89	95	96	90	99	100	99	99	100	100	81	74	85	89	76	60	60	78	84	88	72	98	95	98	88	78	93	89	83	85	83
Ireland	88	91	94	71	99	100	100	100	100	98	90	59	76	92	82	58	69	87	73	92	93	93	81	99	86	81	81	91	88	86	85
Austria	88	95	92	95	99	100	100	100	99	99	84	68	78	89	71	70	67	86	76	93	77	96	88	98	89	84	89	84	78	89	64
France	88	92	92	76	99	100	99	100	99	93	86	72	81	93	73	68	64	80	87	89	94	98	91	95	85	81	75	87	92	86	62
Belgium	88	94	92	68	99	100	99	100	100	95	83	68	79	91	84	65	67	90	78	86	97	94	84	97	86	79	76	90	87	93	70
Canada	88	98	93	73	99	100	99	100	100	96	71	64	79	93	81	71	71	82	72	90	95	92	89	96	86	82	91	78	82	86	82
Slovenia	87	92	99	80	98	100	100	100	99	97	91	71	77	92	60	65	74	77	83	78	71	100	76	97	79	76	89	100	98	90	56
Greece	87	90	100	84	98	100	100	99	100	95	85	62	78	85	67	31	62	94	61	72	83	98	85	100	92	85	100	98	76	71	68
Germany	86	98	95	73	99	100	100	100	100	96	82	75	78	94	66	68	68	81	71	85	78	95	80	95	91	80	75	84	81	87	70
Singapore	86	79	96	39	99	100	100	100	100	99	98	88	75	85	59	86	63	93	74	77	53	95	87	99	93	79	98	94	52	92	97
New Zealand	86	96	90	87	99	100	100	100	99	89	79	60	82	87	73	66	62	70	69	84	93	86	89	96	89	81	80	83	72	85	92
South Korea	86	67	97	79	98	100	99	99	98	94	85	89	79	86	99	87	55	98	100	67	84	95	92	93	98	72	81	63	62	95	83
Denmark	86	96	90	74	98	100	100	100	100	99	81	74	80	94	65	63	72	90	79	81	94	92	68	87	83	78	78	72	79	87	82
Israel	86	95	91	69	99	100	99	100	100	92	85	64	79	92	92	57	62	71	81	85	98	91	97	96	87	75	80	81	59	85	65
Cyprus	85	96	84	84	99	100	97	98	99	100	72	67	84	94	75	65	56	64	68	86	82	94	99	96	92	73	94	71	70	89	75
Qatar	85	83	94	77	99	100	97	98	94	89	62	84	96	99	96	80	67	94	65	86	96	88	93	92	93	88	87	77	63	61	72
Malta	85	100	86	79	99	100	100	99	100	98	68	73	85	85	65	56	57	79	72	91	85	93	87	98	83	83	86	70	74	74	78
Czech Republic	85	96	96	70	98	100	100	100	99	97	88	66	66	81	53	58	72	80	61	75	78	98	68	93	84	69	85	85	81	100	72
UK	85	94	93	64	99	100	98	100	100	92	73	69	79	92	79	58	67	85	77	88	83	87	72	90	76	70	74	86	100	81	76
Portugal	85	81	92	60	98	100	99	100	99	97	91	65	74	87	76	63	59	80	87	70	92	91	86	91	82	72	87	84	75	85	70
Kuwait	82	77	91	60	99	100	100	100	95	96	69	87	93	93	92	82	71	93	55	74	54	91	89	87	95	83	85	92	63	52	63
Croatia	82	85	96	87	97	100	100	100	97	94	75	69	69	87	51	56	67	81	62	61	66	98	69	91	77	73	73	88	74	85	74
Estonia	81	75	98	72	97	100	99	100	100	98	91	71	65	90	75	62	63	72	58	71	43	99	67	95	89	81	66	74	77	90	71
USA	81	97	89	60	98	100	99	100	100	82	69	68	77	90	73	67	71	75	62	83	64	84	88	90	85	76	96	67	62	81	68
Montenegro	81	88	96	90	96	100	91	99	97	97	67	61	65	74	52	36	50	71	56	46	97	100	77	93	94	74	87	66	61	93	62
Lebanon	80	81	88	94	97	100	95	98	97	88	64	89	83	85	50	30	49	88	48	76	72	90	91	90	96	86	79	64	57	55	71
Hungary	80	91	93	89	96	100	100	100	100	95	71	62	60	86	36	64	61	79	56	67	58	94	58	85	74	61	85	81	81	72	79
Poland	80	80	97	68	97	100	100	100	100	99	76	61	59	86	50	51	66	70	61	66	75	99	63	91	78	78	72	78	72	71	64
Saudi Arabia	79	64	81	59	98	100	97	97	93	85	51	88	100	98	92	76	80	86	59	68	87	88	97	86	100	89	81	89	45	55	45
Bermuda	79	96	94	64	99	100	100	100	96	100	75	57	72	93	100	50	40	82	58	68	66	93	69	75	74	77	89	65	52	81	60
Bahrain	79	75	83	67	98	100	98	98	95	86	71	84	91	91	96	50	61	91	65	89	86	89	80	74	88	69	69	52	52	68	68
Slovakia	79	91	92	60	97	100	97	99	100	97	70	70	62	74	46	51	63	79	54	65	65	95	64	93	78	66	68	83	71	71	72
Latvia	78	72	97	65	96	100	100	100	100	93	80	61	66	84	53	54	60	65	45	53	61	99	62	97	87	74	66	66	81	74	63
Taiwan	78	78	95	64	98	100	94	98	80	95	73	83	68	75	93	84	49	85	82	63	60	92	73	91	91	57	79	58	50	62	78
Puerto Rico	77	90	87	49	98	100	99	99	95	89	60	62	70	86	74	60	61	84	68	81	56	85	88	83	82	68	76	55	45	76	59
Lithuania	77	61	97	62	96	100	100	100	100	94	88	65	59	81	59	51	60	61	47	60	65	100	55	86	79	66	65	72	82	76	65
Macedonia	76	74	80	89	95	100	89	98	99	94	54	65	65	60	39	45	46	72	58	44	63	93	80	95	84	89	81	70	61	65	80
Chile	76	72	92	66	97	100	92	99	100	85	69	65	58	93	19	67	54	72	80	70	65	90	82	81	69	56	76	83	53	63	71
Serbia	75	79	93	84	95	100	91	98	100	92	59	53	53	74	35	43	52	82	59	50	72	94	62	85	77	70	72	70	65	63	71

(Figure 2 continues on next page)