

Rethinking Development and Health

Findings from the
Global Burden of Disease Study

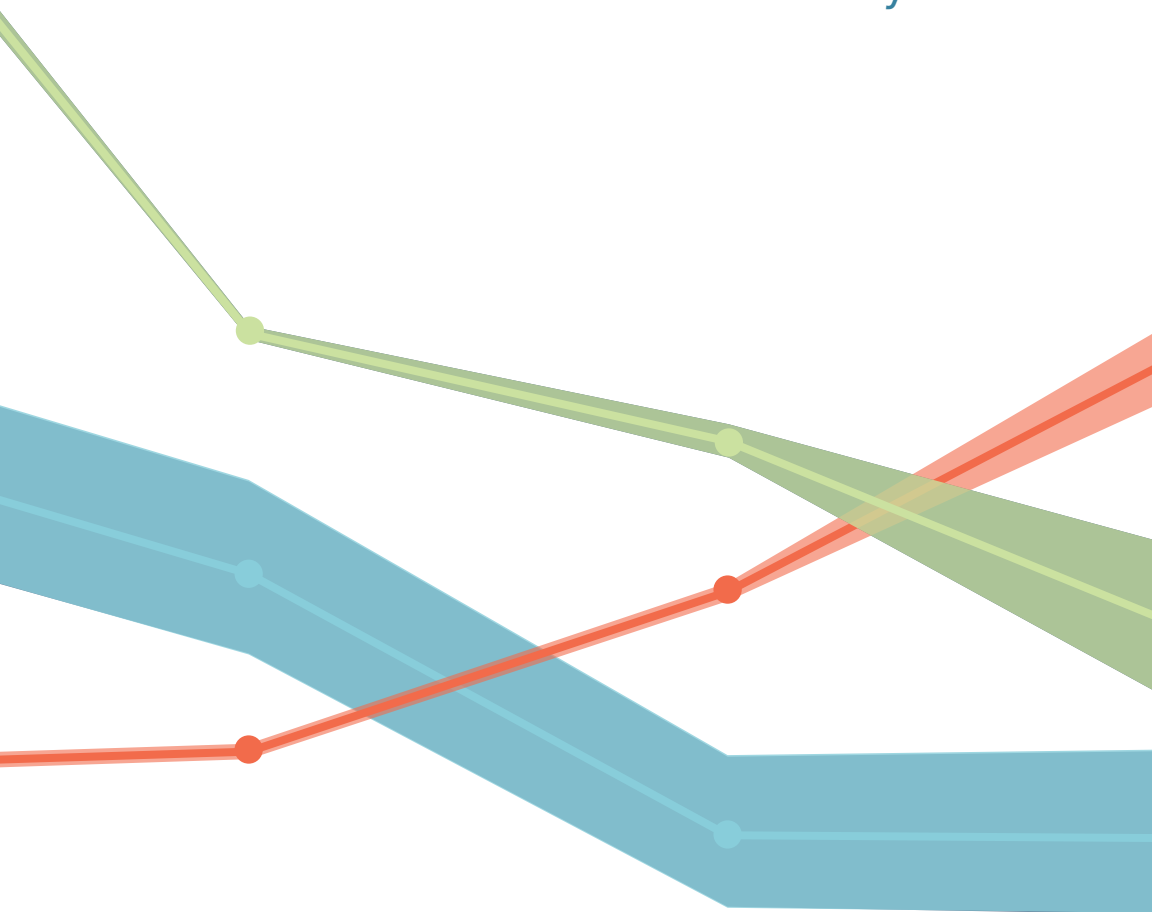


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Rethinking Development and Health

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Global Burden of Disease Study



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About IHME

At the Institute for Health Metrics and Evaluation (IHME), we are diagnosing the world's health problems and identifying the solutions to address them. IHME was launched at the University of Washington in 2007 with funding from the Bill & Melinda Gates Foundation and the state of Washington. Under the leadership of Christopher J.L. Murray, MD, DPhil, researchers began gathering rigorous, scientific evidence on health to launch a new era of independent, objective assessments. Today, IHME is recognized as one of the leading health metrics organizations in the world, and its research is having an impact on health policy globally. IHME makes its findings available so that policymakers have the evidence they need to make informed decisions about how to allocate resources to improve population health.

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Acknowledgments

Rethinking Development and Health: Findings from the Global Burden of Disease Study was prepared by the Institute for Health Metrics and Evaluation.

Findings in this report came from the Global Burden of Disease (GBD) study. A global, collaborative research enterprise, GBD produces comprehensive and comparable annual estimates of disease burden by country, age, and sex for more than 300 causes of disease and injury and 79 risk factors. IHME is the coordinating center for 1,870 GBD experts from 124 countries and three territories.

The research presented in this report is based on seven studies published in *The Lancet* as part of GBD 2015.

The IHME community supported the production of this publication. Christopher Murray, William Heisel, Kate Muller, and Katherine Leach-Kemon offered leadership during the creation of this report. Kevin O'Rourke provided overarching production oversight and publication management. Nancy Fullman and Laurie Marczak reviewed the report's content for scientific accuracy. Adrienne Chew, Pauline Kim, and Michelle Subart fact-checked and edited the report. Dawn Shepard and Sofia Cababa Wood served as the report's graphic designers. This report was written by Sean McKee.

Finally, we would like to extend our gratitude to the Bill & Melinda Gates Foundation for generously funding IHME and for its consistent support of the Global Burden of Disease study.

Glossary of terms

Age-standardization

A statistical technique used to compare populations with different age structures, in which the characteristics of the populations are statistically transformed to match those of a reference population. Useful because relative over- or under-representation of different age groups can obscure comparisons of age-dependent diseases (e.g., ischemic heart disease or malaria) across populations.

Attributable burden

The share of the burden of a disease that can be estimated to occur due to exposure to a particular risk factor.

Disability-adjusted life years (DALYs)

Years of healthy life lost to premature death and disability. DALYs are the sum of years of life lost (YLLs) and years lived with disability (YLDs).

Disability weights

Numerical representations of the severity of health loss associated with a health state. Derived from a worldwide, cross-cultural study to compare the relative severity of health problems, disability weights are numbers between 0 and 1 that are multiplied by the time spent living with a health loss to determine the years lived with disability associated with the cause of that loss.

Healthy life expectancy (HALE)

The number of years that a person at a given age can expect to live in full health, taking into account mortality and disability.

Regions

Groups of countries that are geographically close and epidemiologically similar. The High-income North America GBD region, for example, contains the United States of America and Canada, and the South Asia GBD region contains Bangladesh, Bhutan, India, Nepal, and Pakistan. The GBD regions are themselves grouped into GBD super-regions that possess similar cause of death patterns. The Latin America and Caribbean super-region, for example, contains the Caribbean, Central Latin America, Tropical Latin America, and Andean Latin America regions.

Risk factors

Potentially modifiable causes of disease and injury.

Socio-demographic Index (SDI)

A summary measure that identifies where countries or other geographic areas sit on the spectrum of development. Expressed on a scale of 0 to 1, SDI is a composite average of the rankings of the incomes per capita, average educational attainment, and fertility rates of all areas in the GBD study.

Sequelae

Consequences of diseases or injuries.

Summary exposure value (SEV)

A measure of a population's exposure to a risk factor that takes into account the extent of exposure by risk level and the severity of that risk's contribution to disease burden.

Uncertainty intervals (UIs)

A range of values that reflects the certainty of an estimate. Larger uncertainty intervals can result from limited data availability, small studies, and conflicting data, while smaller uncertainty intervals can result from extensive data availability, large studies, and data that are consistent across sources.

Years of life lost (YLLs)

Years of life lost due to premature mortality.

Years lived with disability (YLDs)

Years lived in less than ideal health. This includes health loss that may last for only a few days or a lifetime.

Report highlights

- The world is in the midst of an epidemiological transition. As countries increase their levels of development, their communicable disease burdens are declining and their life expectancies are rising. This transition is affecting disease burden, disability burden, and health risk factor exposure in complicated ways.
- While development drives many positive changes in health outcomes, certain diseases (such as chronic kidney disease) and risk factors (such as obesity) tend to worsen with development.
- Development drives, but does not determine, health. While more developed countries tend to be healthier than less developed ones, some countries are much healthier than expected given their level of development, such as Ethiopia, China, and Spain.
- From 1990 to 2015, child and maternal mortality declined substantially. In particular, the international community's focus on child survival appears to be reaping rewards, since child mortality in 2015 was lower than expected given current levels of development.
- The burden of communicable diseases declined from 1990 to 2015, with the bulk of that achievement being driven by reductions in the burden of malaria and HIV/AIDS since 2005.
- Overall, the magnitude of the burden of non-communicable causes of disease and injury is rising. The burden of some non-communicable diseases has declined, but generally not quickly enough to overtake rates of population growth.
- The rate of burden from nonfatal causes of disease and injury was flat from 1990 to 2015. As populations grow and increase in average age, however, the total burden of disability is rising quickly.
- Exposure to poor sanitation, indoor air pollution, and childhood undernutrition has dropped, resulting in dramatic declines in the burden of diarrhea and pneumonia in children.
- Exposure to several risk factors linked to development increased markedly – placing them among the most pressing targets for intervention – from 1990 to 2015. These include obesity/overweight, high blood sugar, ambient air pollution, and drug use.

What is the Global Burden of Disease study?

The aims of the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) are simple. Everyone, all over the world, deserves to live a long life in full health. In order to achieve that goal, the world's decision-makers and development partners need to make the best possible decisions when determining how to allocate money, talent, and attention to combat health issues. And in order to do that, policymakers need accurate and accessible data on the relative harm health problems cause across time, geography, age, and sex. GBD 2015 provides exactly that.

A worldwide collaborative effort to measure the impact of health problems on people, GBD is coordinated by the Institute for Health Metrics and Evaluation at the University of Washington in Seattle. Data for the project are collected and analyzed by 1,870 collaborators from 124 countries and three territories. GBD uncovers the toll of early death and disability caused by more than 300 diseases and injuries in 195 countries and territories from 1990 to the present. Its methods and metrics emphasize comparability among causes that kill and causes that disable (details are available below and in the Methodological appendix at the end of this report).

The GBD is frequently updated using new data to improve past and present estimates of disease burden. GBD 2015 represents a major update to the study – it incorporates the largest amount of data, from the greatest number of collaborators, with the most advanced estimation methods in the project's history while adopting leading standards in transparency and openness.

History

In the early 1990s, Drs. Christopher Murray and Alan Lopez, the GBD study's original authors, realized that adding up all the deaths attributed to different causes by cause-specific analyses yielded a number greater than the number of global deaths per year. To address this, they set about producing a more cohesive estimate of worldwide deaths while also measuring the impact of non-lethal health problems. The resulting study, which attempted to show the relative burden caused by seemingly dissimilar health problems such as heart disease, road accidents, and low back pain, had a profound impact on health policy and agenda-setting throughout the world.

Following those initial efforts, the ideas and techniques of the GBD study have been continually refined. The first major peer-reviewed GBD publications arrived in 1997, when *The Lancet* published a series of articles by the GBD authors estimating mortality and disability around the world.¹⁻⁴ In 1998, the World Health Organization established a Disease Burden Unit that published regular additions to the GBD estimates starting in 2000.

The GBD study took a leap forward in 2010. For the first time, collaborators revised estimates for the time from 1990 to the most recent year possible, replacing what had been a snapshot of global health with a quantitative narrative of health trends over time. In addition, while the early work on GBD was performed by a

small number of individuals, GBD 2010 was a truly collaborative effort. Coordinated by IHME, GBD 2010 brought together work from 422 researchers around the world while making considerable advances in methods and computing techniques. GBD 2013 marked another leap forward, but GBD 2015 is the most comprehensive GBD effort to date.^{5–15}

The GBD data catalog

The GBD study's comprehensiveness is due in part to its data catalog. GBD 2015 estimates are generated using the largest health data library in the world. GBD researchers and collaborators collect and clean health data from vital records registries, censuses, surveys, and studies from around the globe. Those data are then fed into algorithms that generate the GBD estimates while also using new data to improve the accuracy of past estimates. So, for example, if a newly available 2015 study on the incidence of diabetes in one region of Mexico becomes available, those data may improve estimates of diabetes incidence made in 2010 and 2013 (and earlier).

The GBD metrics emphasize comparability

Comparing the burdens of different diseases has been difficult in part because the numbers traditionally used to describe the health of populations were expressed in different units: raw numbers, rates per 1,000 or 100,000 people, indexes that combine related measures of health, and so on. Most of the metrics created for the GBD study, by contrast, are expressed in the same unit: years. This aids in comparing the burden of seemingly disparate health problems, from malaria to schizophrenia.

The principal metric of the GBD study, the disability-adjusted life year (DALY), helps decision-makers compare the impact of different diseases and injuries not just in terms of early death but also in terms of suffering. DALYs are made up of two components: years of life lost (YLLs) and years lived with disability (YLDs).

YLLs measure all the time people lose when they die prematurely before attaining their ideal life expectancy. Ideal life expectancy is based on the highest life expectancy observed at every age around the world. As an example, for GBD 2015 the ideal life expectancy for males at age 20 is 61.5 (which adds up to a total lifespan of 81.5, observed in Andorra). Therefore, if a young man in Nigeria (or Japan, or Venezuela, and so on) dies in an accident at age 20 in 2015, GBD measures that as 61.5 YLLs.

YLDs measure years of life lived with any short- or long-term condition that prevents a person from living in full health. They are calculated by multiplying an amount of time (expressed in years) by a disability weight (a number between 0 and 1 that quantifies the severity of a disability). If a person lives one year with a disability, then, the YLD measure of that person's disability would be less than one, while the YLL for a year not lived would be exactly one.

Adding together YLLs and YLDs yields DALYs, a measure that portrays in one metric the total health loss a person experiences during their life. Adding all instances of health loss in a population together – and thereby estimating burden

of premature death and disability – enables policymakers and researchers to make comparative assessments of global population health. More information on GBD metrics is available in the glossary at the end of this report, on the IHME website, and in the GBD 2015 papers published in *The Lancet*.^{16–21}

Introducing the Socio-demographic Index

The 2015 version of GBD includes a new metric that further enhances comparability of health data: the Socio-demographic Index (SDI). Countries that were previously referred to as “developing” have, in recent decades, begun to experience health problems increasingly similar to those of countries referred to as “developed” – a process often called “the epidemiological transition.” In this transition, a population experiences longer life expectancies, declining deaths due to infectious disease, and increasing health problems due to non-communicable diseases (such as ischemic heart disease or diabetes) and age-related disability. As countries become more similar in this way, it makes less sense to refer to them using the binary of “developed” and “developing.”

Call for GBD collaborators

The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) is the most comprehensive effort to date to measure epidemiological levels and trends worldwide. With 1,870 collaborators from 124 countries and three territories currently participating in the study, we are always working to expand and strengthen the GBD collaborative network.

GBD collaborators have expertise in all-cause mortality estimates; specific diseases, injuries, risk factors, and impairments; and the epidemiological profile of individual countries. They provide timely feedback related to interpretation of GBD results, data sources, and/or methodological approaches pertaining to their area of expertise. GBD collaborators – many of whom have co-authored GBD publications – include researchers, clinicians, epidemiologists, global health practitioners, demographers, and statisticians, among others.

Enrollment is now open for the next round of GBD. We invite you to apply to be a GBD collaborator if you are interested in participating in this next iteration.

For more information about the GBD’s history, management, and oversight, and to read the GBD protocol, please visit the following URL:

<http://www.healthdata.org/gbd/call-for-collaborators>.

To contact the GBD Management Team, please email gbdsec@uw.edu.

Therefore, GBD refers to countries by their SDI, a new indexing metric created by the GBD team for the 2015 update. GBD researchers determined that a few factors that have been established by researchers as contributing to population health – a country's income per capita, average level of educational attainment, and fertility rate – could be combined to create a simple-but-powerful measure of overall development. Classifying countries by SDI allows the generation of a fine-grained spectrum of development (instead of either/or) by which they may be compared. Figure 1 shows the SDI quintile rankings of the world's countries.

Uncertainty

Aside from comparability, another important principle of GBD is reporting uncertainty. The results produced by GBD 2015 and highlighted in the following pages are estimates. Estimates form the backbone of many of our societal discussions. The unemployment rate is an estimate. So are things like political poll numbers and weather forecasts. Because they are not exhaustive counts, all of these numbers contain some measurement error. Therefore, it is most scientifically sound to present ranges of estimates known as uncertainty intervals. Historically, publishing uncertainty intervals has not been a common practice in global health. But all of the GBD estimates include uncertainty intervals.

An uncertainty interval is the numeric range above and below an estimate that is likely (usually with a probability of 95%) to contain the correct value. When, for example, GBD 2015 estimates that ischemic heart disease caused 8,916,964.20 deaths in 2015, included with that estimate is an uncertainty interval of 8,751,616.73 to 9,108,849.95. This means that GBD researchers believe the true estimate of people who died from ischemic heart disease in 2015 is 8,916,964.20, but they have also have calculated a 95% likelihood that the actual number of people in the world who died of ischemic heart disease in 2015 is between 8,751,616.73 and 9,108,849.95.

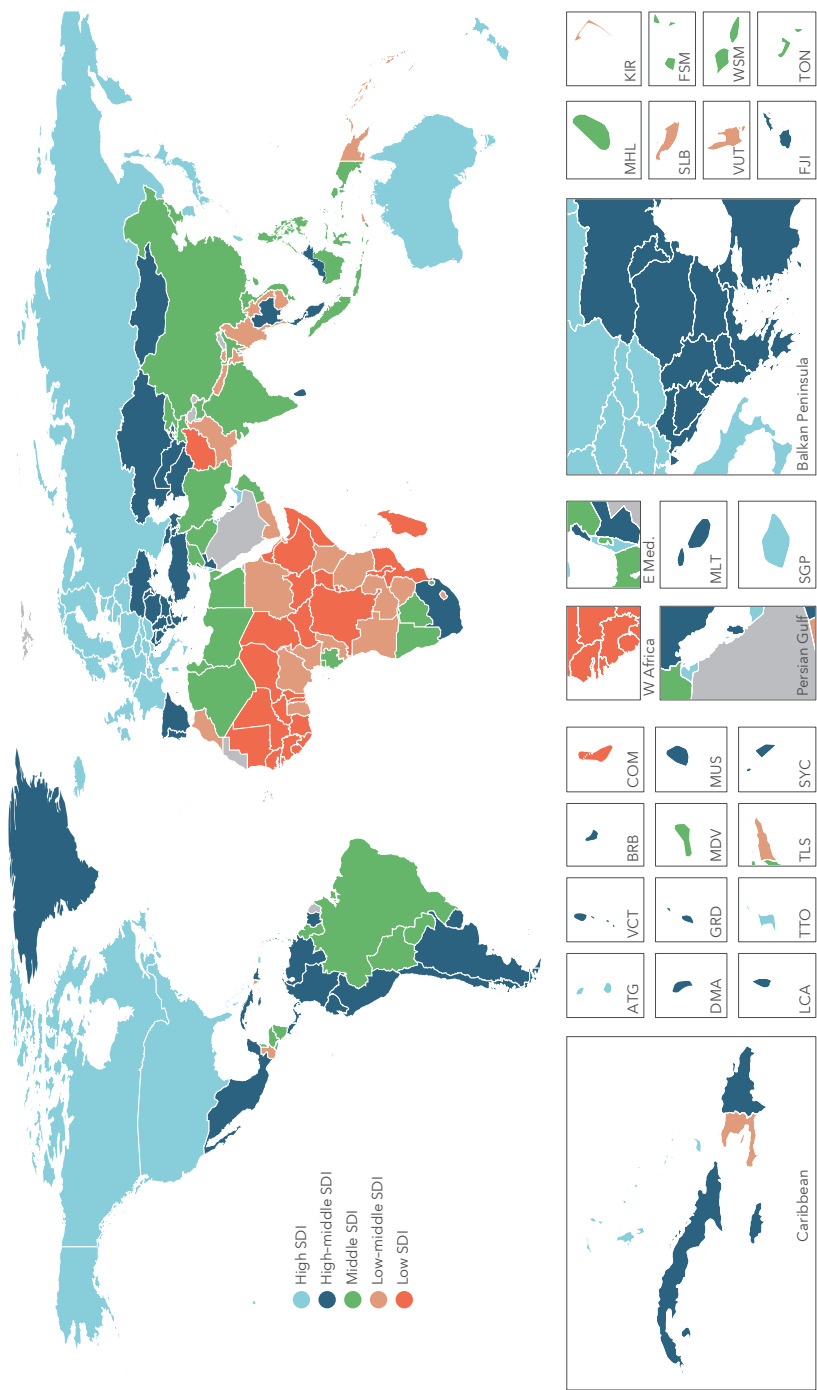
Uncertainty intervals allow researchers to acknowledge shortcomings in available data. Having large amounts of high-quality data makes it possible to produce an estimate with narrow bands of uncertainty, while having smaller amounts of reliable data leads to wider bands. The width of the uncertainty intervals cited in GBD 2015 varies greatly. Those variations indicate to researchers and readers when health data availability and quality are robust or in need of improvement.

In order to enhance readability, uncertainty intervals are not presented within this report. Uncertainty intervals for all GBD estimates may be easily accessed using the tools that are publicly available on IHME's website.

Transparency, openness to critique, and GATHER

The desire for openness about data quality exemplified by highlighting uncertainty intervals has driven GBD 2015 to take a decisive step toward methodological openness by complying with the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER). Developed by representatives from IHME, the World Health Organization, the Harvard and Johns Hopkins Schools of Public Health, the University of Oxford, the London School of Hygiene and Tropical Medicine, the University of Ottawa, and two medical journals, *The Lancet* and *PLOS Medicine*,

Figure 1
SDI quintiles by country, 2015



GATHER codifies standards for disclosing how health estimation research is done. Researchers using GATHER agree to disclose definitions of health indicators, provide access to statistical source codes, make data and analyses publicly available, and more. (The full guidelines, rationale, and other information on GATHER are available at <http://gather-statement.org>.) GATHER is meant to aid in results replication and collaboration – two cornerstones of scientific inquiry that allow for the continuous methods refinement and wide basis of expertise so important to the GBD process. In keeping with GATHER, all data citations, code, analyses, and results associated with GBD 2015 are available on the IHME website.

Tools for accessing GBD 2015 data

There are several tools available via the IHME website that facilitate the use of GBD 2015 information. These tools allow users to access the results of GBD 2015 and information on the data that contributed to GBD 2015. When the usage agreements with owners of raw data permit IHME to share those data, we do. In cases where IHME does not own the distribution rights for a set of data, it provides ownership information so that researchers may contact data owners directly.

IHME provides pathways to data that it uses, but does not own, via the GHDx, which contains citations and source information for an enormous and ever-growing number of surveys, censuses, and other health-related data. Because the GHDx is searchable by country, data type, collecting organization, topic, and other characteristics, it is an excellent starting point for anyone seeking out data on the world's health. It can be accessed at <http://ghdx.healthdata.org>. For GBD 2015, the GHDx will host a tool at <http://ghdx.healthdata.org/gbd-2015> that lets users explore GBD input sources cataloged in the GHDx by GBD component, location, cause, risk factor, and covariate.

GBD 2015 estimates are available for download through the GBD Results Tool at <http://ghdx.healthdata.org/gbd-results-tool>. This web tool includes numerous ways to examine the GBD results by viewing and downloading estimates for different locations, diseases, risk factors, and so on. The tool allows for viewing data in the form of text or graphs and for downloading data via .csv files.

In addition to GBD 2015 input data information and results, IHME hosts on its website GBD Compare, a data visualization capable of generating compelling graphic representations of GBD estimates. These tools allow anyone to access and explore the full set of GBD estimates using maps, bar charts, tree maps, and other visuals. Here, GBD results can be examined by disease, age group, sex, country (sub-nationally for many countries), and in many other ways. We invite anyone to load GBD Compare into their web browser and explore.

GBD 2015 results

The GBD 2015 study shows that, from 1990 to 2015, the world as a whole has been undergoing an epidemiological transition. The nature of that transition is discussed below in a brief overview of some key GBD 2015 results. Since the GBD 2015 study's results consist of over 2 billion estimated data points, this report only touches on a few of the project's most widely applicable, biggest-picture conclusions.

The estimates, tables, and figures in this report come from datasets and visualization tools that are available for public access on the IHME website. Details about how the estimates were generated may be found in the Glossary and Methodological appendix of this report, as well as on the IHME website and in the GBD 2015 articles published in *The Lancet*.^{16–21}

The global epidemiological transition

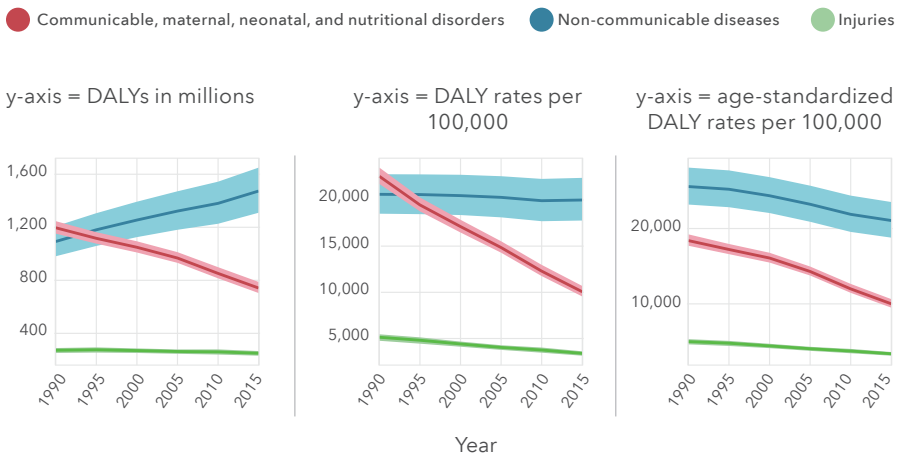
The concept of epidemiological transition is not new. Rather, it is an established pattern that has been tied to development. As countries move up the spectrum of development, their mortality rates due to communicable, maternal, neonatal, and nutritional diseases decline. That prompts a shift in disease burden: as more people live into adulthood, the average age of the population increases and its disease burden shifts to non-communicable diseases and disabilities. In countries that have undergone the epidemiological transition, improvements in treatment and prevention of the disease burden associated with aging have not kept pace with increases in the population affected by that burden, so the overall DALY burden on the health systems of high-SDI countries has continued to increase.

These phenomena are discernible in Figure 2, which illustrates the worldwide trends of different causes of disease burden, expressed in DALYs, from 1990 to 2015. The left side of the figure shows that the absolute DALY burden of communicable, maternal, neonatal, and nutritional diseases is declining and the burden of non-communicable diseases is rising – exactly what would be expected in a worldwide population that is simultaneously growing, aging, and increasing in development level. The DALY rate for non-communicable diseases, however, has remained flat and the age-standardized DALY rate (the right side of Figure 2) for those diseases has declined. What Figure 2 does not show, though, is that the rate of the increase of the adult population in many higher-SDI countries outstrips the overall rate of decline in the age-standardized non-communicable disease burden, which means that the overall non-communicable disease burden that must be addressed by the world's health systems has grown.

The increasing burden of non-communicable diseases in higher-SDI countries illustrates that development, while useful in addressing the burden of communicable, maternal, neonatal, and nutritional diseases, does not solve every population health problem. In fact, some disease burdens and the risks associated with them – as detailed in this report – are rising in higher-SDI countries. Moreover, as demographic transitions are widely expected to continue around the world, the burden of non-communicable diseases is likely to continue expanding.

Figure 2

Trends in DALYs for communicable, maternal, neonatal, and nutritional diseases; non-communicable diseases; and injuries, 1990–2015



Determining how to address that burden will be a key task of health systems during the coming decades.

The GBD 2015 study can aid that effort by highlighting countries that have shown better-than-expected results – particularly when viewed in relation to their levels of development – in tackling the disease burdens faced by their populations. While it is generally true that countries with higher SDIs experience better population health, that is not at all true on a case-by-case basis. It may be that by examining the countries whose health metrics outperform their SDI, health researchers can establish how to increase health regardless of SDI. For example, since we now recognize many of the risk factors related to non-communicable disease burden in higher-SDI countries, by identifying how best to address those risks, low- and middle-SDI countries may have the ability to adopt policies to circumvent the mistakes made by others as they progressed along the SDI spectrum. Ultimately, it may be possible to de-couple health from development, paving the way for all people from all levels of development to live their lives in full health.

Health outcomes often differ from SDI-based expectations

As an increasing number of countries undergo epidemiological transition, the nature of the disease burden confronted by those countries has been changing. One way in which policymakers can assess the relative success of countries in confronting the changing burden of disease is by comparing the population health observed in countries around the world with the health outcomes we would expect to find based solely on those countries' SDI levels.

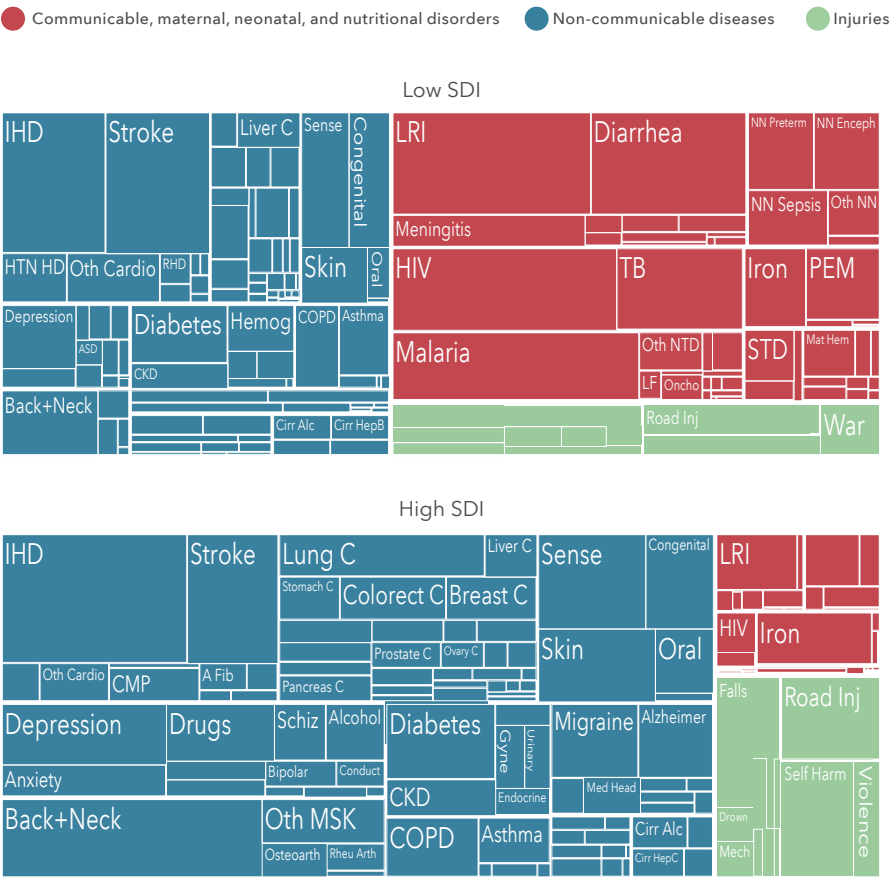
Countries at different levels of development generally face differing burdens of disease. This tendency is most starkly illustrated by examining the disease burden faced by countries in the highest SDI quintile versus those in the lowest, as in Figure 3. Note that the patterns displayed track well with the overall narrative of epidemiological transition: low-SDI countries face considerably higher burdens from communicable, maternal, neonatal, and nutritional diseases (e.g., HIV/AIDS, maternal hemorrhage, neonatal sepsis, and protein-energy malnutrition, respectively), while high-SDI countries suffer most from non-communicable diseases such as ischemic heart disease, stroke, diabetes, and musculoskeletal disorders.

What's new in GBD 2015

Although GBD collaborators are always working to improve the methods used and estimates resulting from the project, each update of GBD represents considerable scientific advancement. Compared to the GBD 2010 and 2013 studies, new elements of GBD 2015 include:

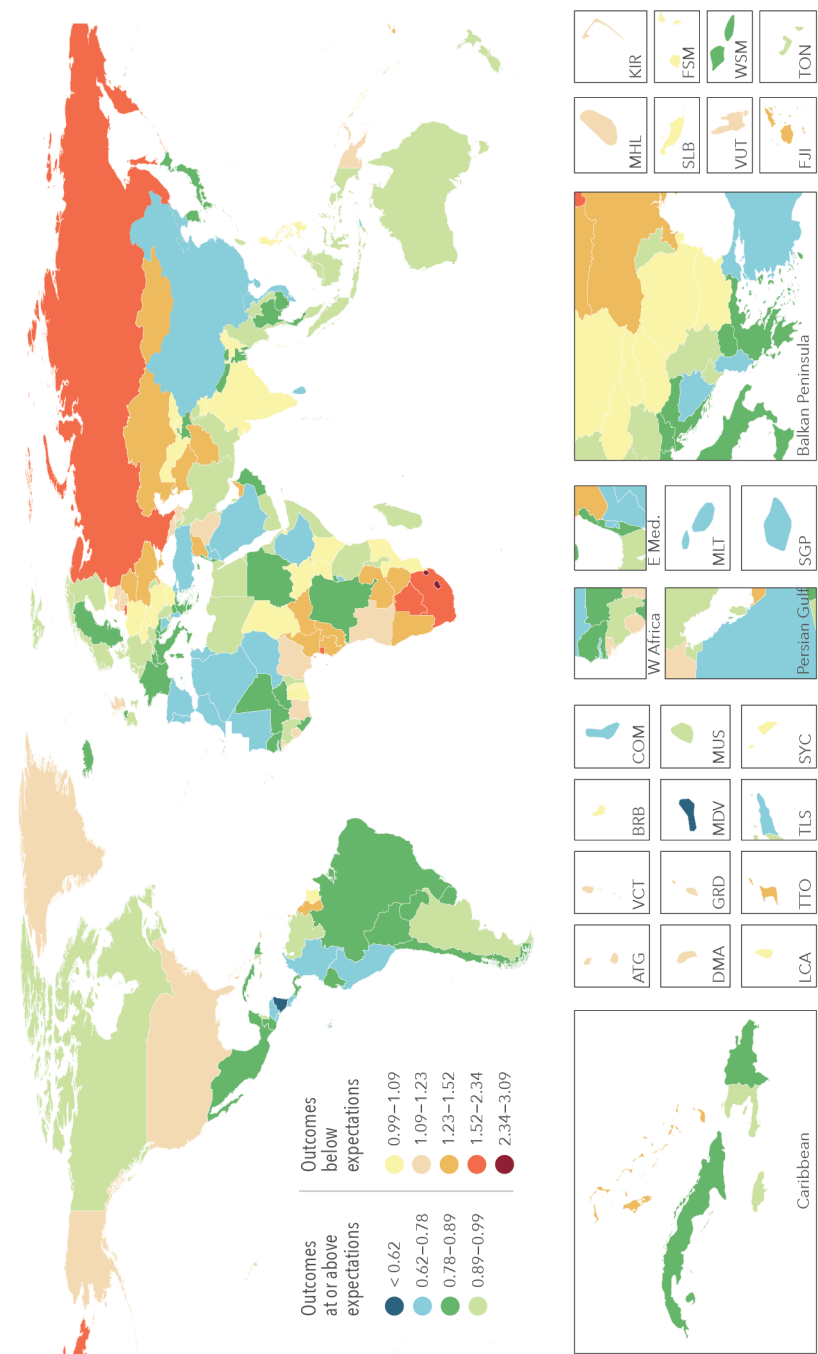
- **Estimates that supersede those from 2010 and 2013.** As more health data and research become available, the GBD estimates improve for current years but also for past years. For example, GBD 2015 estimates of YLLs due to tuberculosis in the year 2000 are more robust than those made in GBD 2010 or 2013.
- **A larger collaborator network.** Between GBD 2013 and 2015, the GBD collaborator network grew from 1,008 researchers based in 93 countries to 1,870 collaborators from 124 countries and three territories.
- **New subnational assessments.** GBD 2015 includes estimates at the level of provinces, states, or districts in Brazil, China, India, Japan, Kenya, Mexico, Saudi Arabia, South Africa, Sweden, the United Kingdom, and the United States. The fine-grained detail offered by these estimates can help allocate resources between particular regions, provinces, or even cities.
- **Greater transparency.** GBD 2015 adheres to the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER), a new set of standards designed to increase openness, accuracy, collaboration, and replication of health estimates. The GATHER standards are discussed in more detail elsewhere in this report and at <http://gather-statement.org>.
- **A different way of classifying countries' levels of development.** The SDI metric introduced in GBD 2015 creates a more nuanced picture of a country's level of development than binary descriptors like rich and poor or developed and developing. By tracking health outcomes along with SDI, decision-makers can identify countries that outperform their development level and seek to replicate those countries' health solutions.

Figure 3
Age-standardized DALYs, low-SDI versus high-SDI countries, 2015



The factors that inform SDI – income per capita, average level of educational attainment, and fertility rate – drive improvements in health outcomes, so we should expect that a country’s SDI level will match its relative rank in observed population health outcomes. While this is true in general, it is not true in every case, as Figure 4 indicates. Some high-SDI countries have worse-than-expected health outcomes (Russia and the United States, for example), while others have better-than-expected outcomes (such as a handful of countries in Western Europe). Several low-SDI countries underperformed their SDI level (Afghanistan, the Central African Republic, and Côte d’Ivoire, for example), but many low-SDI countries outperformed their SDI, among them Niger, Ethiopia, Mauritania, Burkina Faso, and Senegal. Some middle-SDI countries, such as China, did better than expected, while others, such as Guyana, did worse.

Figure 4
 Ratio of age-standardized DALYs observed to those expected based on SDI level, 2015



The analysis of observed-versus-expected health outcomes illustrated in Figure 4 can also be performed for specific population health indicators and even specific diseases. GBD 2015 makes clear, for example, that the world as a whole has succeeded at reducing mortality rates for children under age 5 at a rate faster than would be expected based on SDI. Figure 5 shows this progress. The two lines, representing expected child mortality based on worldwide SDI and observed child mortality, crossed in 1999. Since then, under-5 child mortality has been decreasing faster than expected based on SDI.

When it comes to extending life expectancy at birth, progress from 1990 to 2015 was more mixed. Figure 6 breaks down observed versus expected life expectancy at birth by region. The black line in the graph represents the life expectancy expected based on SDI, while the colored dots represent yearly observed life expectancy by region from 1980 to 2015. A few regions outperformed their SDI-expected life expectancy and a few underperformed it. Perhaps the most surprising result is that high-SDI countries performed slightly less well than expected overall. Also, the extensive attention paid to issues affecting sub-Saharan Africa, such as child and maternal mortality and making HIV/AIDS treatment more readily available, seems to have had a positive effect, as the past decade has shown sub-Saharan African life expectancy rising toward its SDI-expected level.

There are many other similar cause- and country-specific analyses that can be carried out using GBD data. Such analyses can make clear where countries have experienced success, such as in the achievement of lower-than-expected burden from preterm birth complications in Ethiopia and Kenya, or from self-harm in Malaysia and China. They can also highlight troubling patterns that demand attention, such as the higher-than-expected burdens from drug use disorders in the US and Australia, or from interpersonal violence in Brazil, Colombia, El Salvador, Guatemala, Honduras, and Venezuela.

Figure 5
Death rate observed versus that expected based on SDI level, ages 0-5, global, 1990-2015

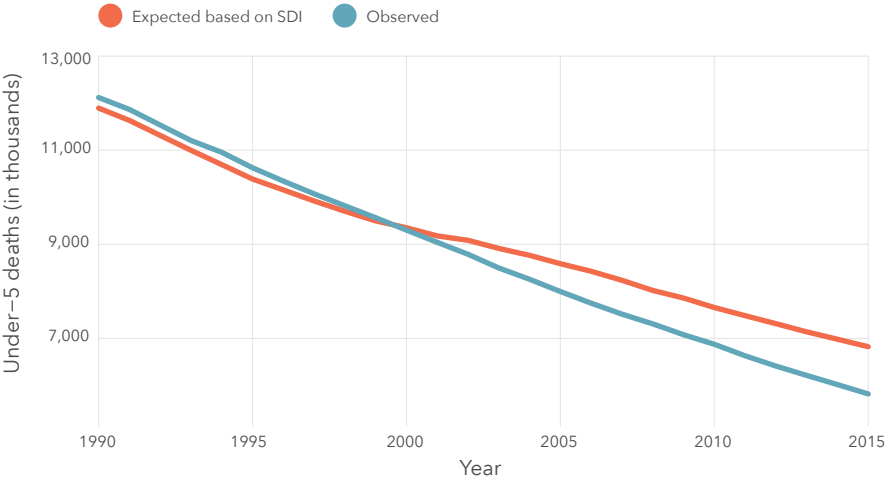
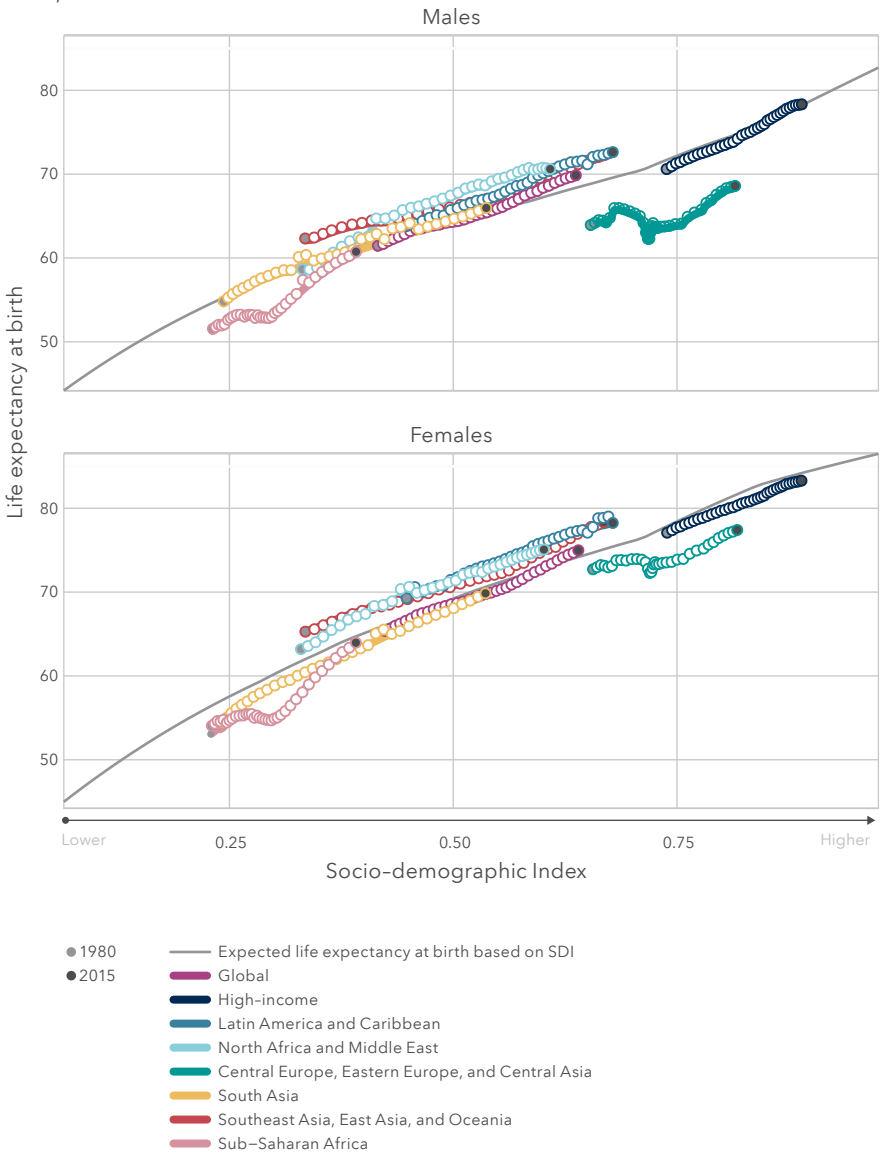


Figure 6
Life expectancy observed by region compared to that expected based on SDI level, 1980-2015



As the world's health policymakers work to reduce the burden of disease, examining places with higher- and lower-than-expected disease burdens may prove a useful tool for determining which techniques should be embraced and which mistakes may be avoided.

People are living longer lives and dying at lower rates

As an increasing number of countries around the world undergo epidemiological transition, people within them are dying at lower rates and living to older ages. Life expectancy at birth rose steadily between 1990 and 2015. Figure 7 depicts this trend in two main ways. This chart depicts life expectancy at birth for females and for males around the world from 1990 to 2015. The clear trend that emerges is one of steady improvement, although at different levels for each sex. Males around the world in 2015 continue, as they long have, to live shorter lives than females.

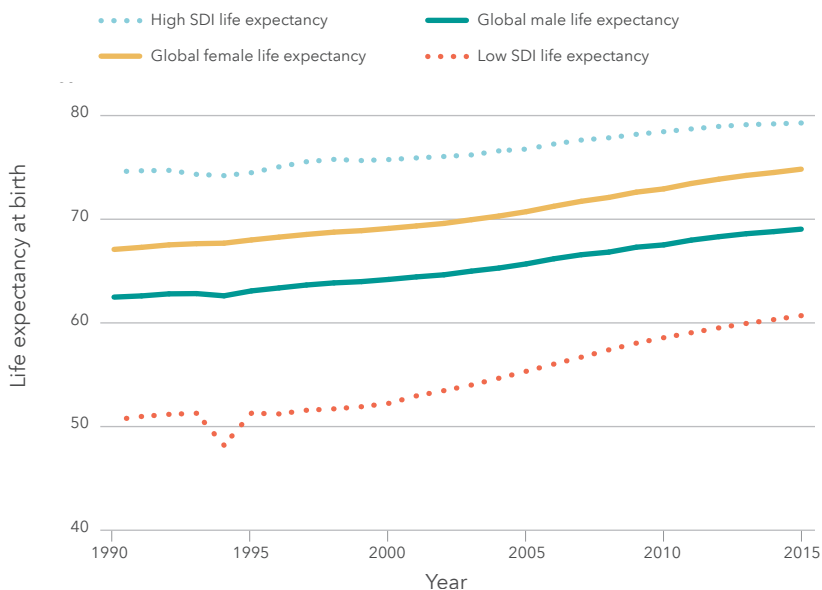
Figure 7 also includes two other lines: one depicting life expectancy trends in high-SDI countries (that is, countries in the top SDI quintile illustrated in Figure 1) and those with low ones (in the bottom quintile). While life expectancy has improved around the world between 1990 and 2015, it remains the case that people in more developed countries can generally look forward to longer, healthier lives than people in less developed countries.

Mortality for mothers and young children is going down

One of the factors driving the increases in life expectancy at birth depicted in Figure 7 is better health outcomes for mothers and young children. International health policymakers have emphasized maternal and child well-being because it has long been clear to epidemiologists that improving the health of mothers and young children has huge positive effects on population health. This is because both groups face health risks that are acute but also time-bound. Young children have relatively

Figure 7

Life expectancy at birth, global, 1990–2015



delicate bodies and immune systems, but after age 5 their resilience increases. Likewise, pregnancy and childbirth pose heightened health risks for women, but those risks mostly dissipate shortly after giving birth. Therefore, targeting efforts to help children and women survive these time-bound risks can have an immense payoff. That was, in part, the inspiration behind the United Nations Millennium Development Goals (MDGs).²²

The MDGs, focused on health, nutrition, and equity, set ambitious goals for child and maternal health to be achieved between 1990 and 2015. They proposed that the world reduce the under-5 child mortality rate by two-thirds and the maternal mortality ratio (the number of maternal deaths per 100,000 live births) by three-quarters. While the MDGs for maternal and child health were not met by all countries, the progress made toward those goals was immense. Figure 8 makes clear that the mortality rate for children under 5 dropped by half between 1990 and 2015. The global maternal mortality ratio declined from 282 per 100,000 in 1990 to 196 per 100,000 in 2015 – a 30% decrease (see Figure 9). These estimates indicate that millions of lives have been saved in pursuing the MDGs. An even more ambitious set of goals, the Sustainable Development Goals (SDGs), has been established to build upon and expand the gains made in pursuit of the MDGs.

Figure 8
Global mortality rate, ages 0-5, 1990-2015

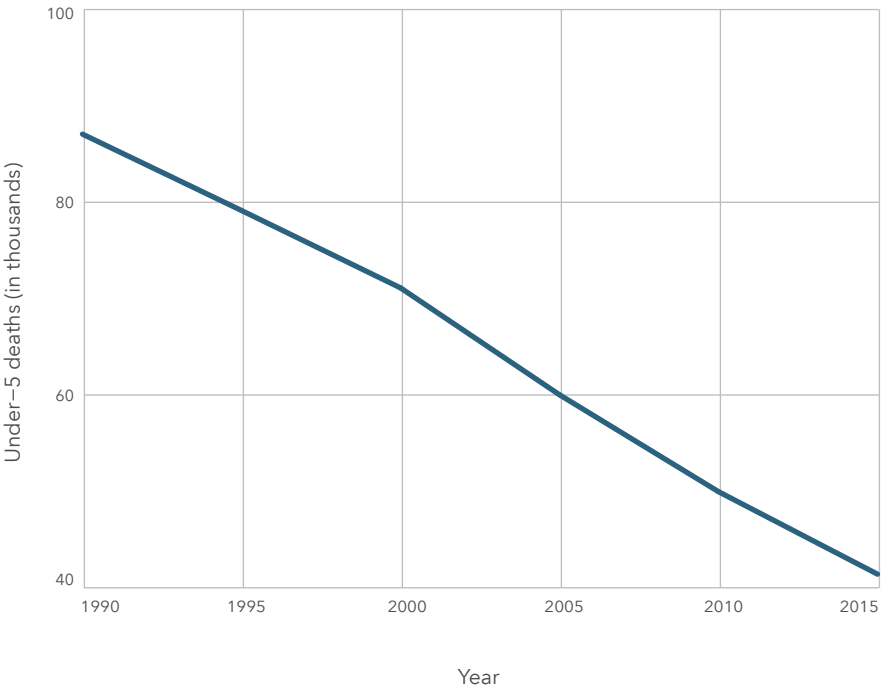
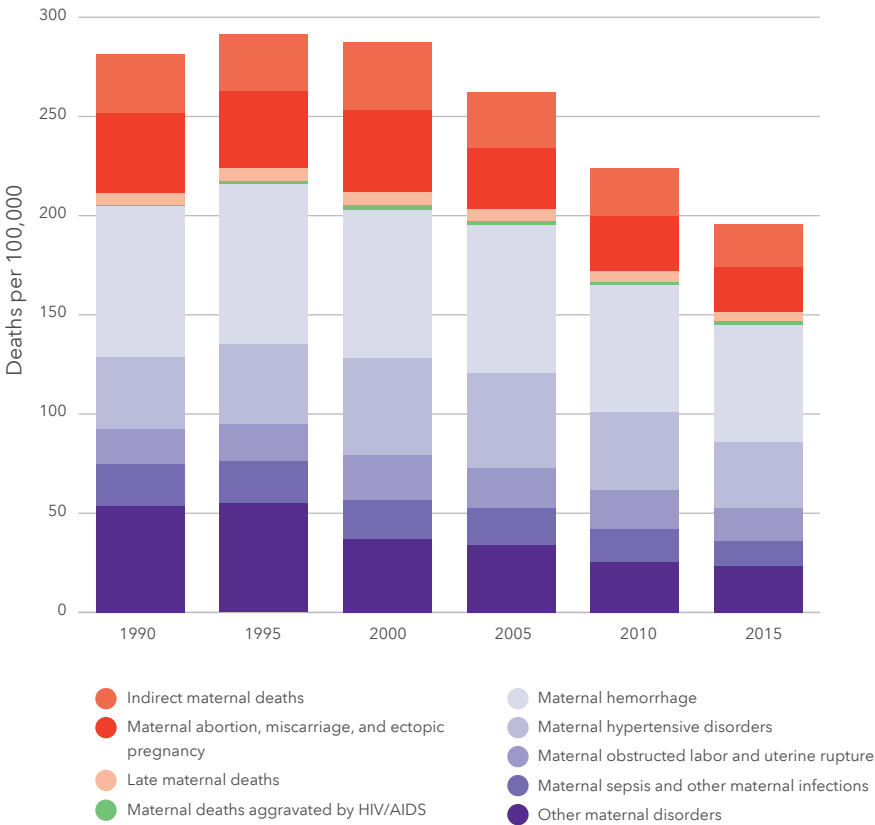


Figure 9
Maternal mortality ratio (MMR), global, 1990–2015



The burden of communicable diseases is declining

The epidemiological transition under way around the world is due in part to the considerable efforts that the global health community has undertaken toward reducing the burden of communicable diseases. One of the MDGs was devoted to combating HIV/AIDS, tuberculosis, and malaria; the health-focused SDGs propose tackling those diseases plus neglected tropical diseases (NTDs) and hepatitis. Those efforts have borne results. Fewer people are dying from communicable diseases, thereby allowing them to survive into old age while living productive lives. The resulting increase in average population age is one of the key characteristics of the epidemiological transition.

Analyzing the different diseases composing this category reveals a theme: burden from communicable diseases has fallen appreciably but remains concentrated in sub-Saharan Africa and South Asia in countries in the low- and low-middle-SDI quintiles. The drop in communicable disease burden can be seen most prominently

in two disease groupings in sub-Saharan Africa: malaria and NTDs, and HIV/AIDS and tuberculosis. Figure 10 compares the burdens from malaria and NTDs in sub-Saharan African regions in 1990 and 2015. The progress in that time has been remarkable: the age-standardized DALY rate for malaria dropped by almost 55%. Burden from most NTDs declined as well, with especially substantial progress made in trypanosomiasis and onchocerciasis.

The burden of HIV/AIDS in sub-Saharan Africa has also declined recently. As shown in Figure 11, that burden rose substantially from 1990 to 2005, but then declined by half between 2005 and 2015. (2005 was the peak of the HIV/AIDS epidemic, when drugs to treat those diseases began to be widely distributed and

Figure 10
Age-standardized DALYs per 100,000 due to malaria and NTDs, sub-Saharan Africa, 1990 versus 2015

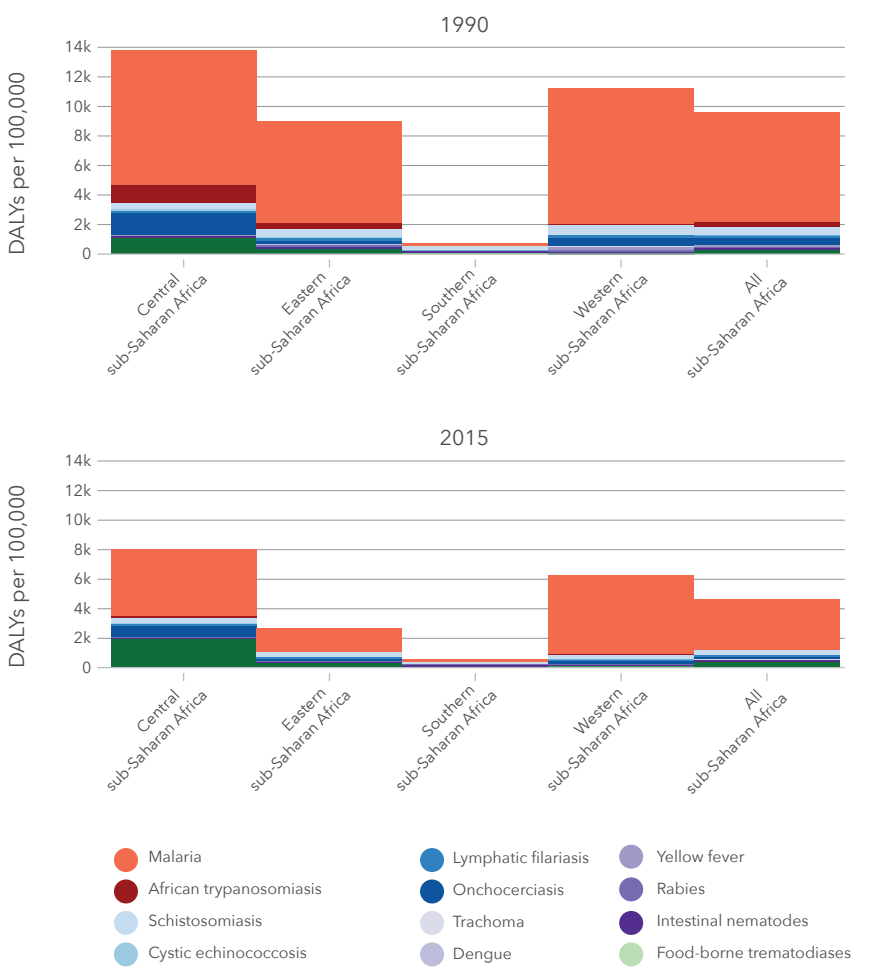
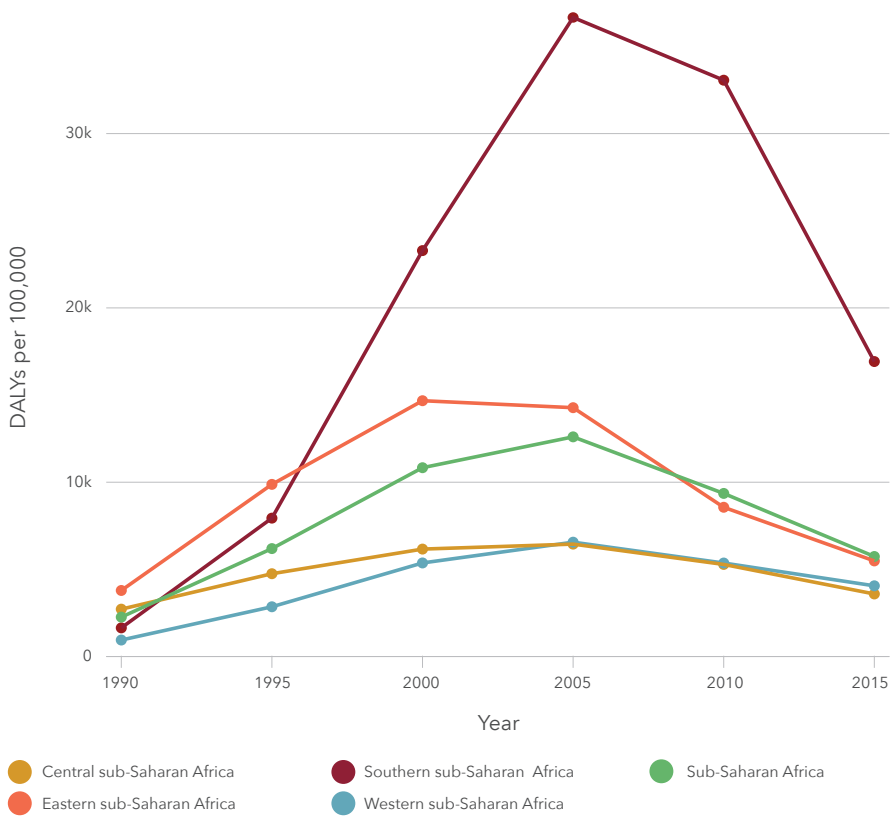


Figure 11
 Age-standardized DALYs per 100,000 due to HIV/AIDS, sub-Saharan Africa, 1990–2015



mortality rates, which had been rising up until 2005, began to decline.) While the burden of infectious diseases – especially in sub-Saharan Africa – remains high, it has dropped impressively over the last 25 years, making that region a key factor in the global decline in communicable disease burden. That decline also highlights the immense impact made by cost-effective communicable disease treatment and prevention efforts as well as the need for continued investment to sustain those efforts.

Causes of disease burden are shifting from communicable to non-communicable diseases

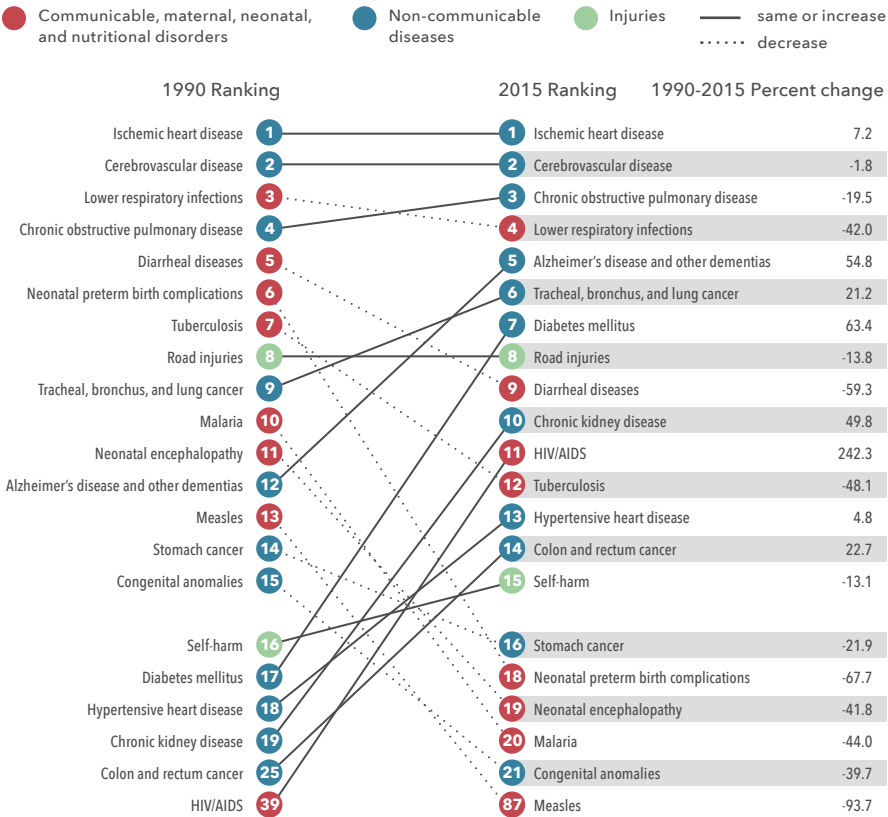
Fewer people are dying in 2015 from communicable diseases such as lower respiratory tract infections, diarrheal diseases, malaria, and NTDs than ever before (see Figure 12). At the same time, non-communicable diseases that appear with age, such as Alzheimer’s disease, hypertensive heart disease, and many cancers, are

killing more people. Ischemic heart disease, stroke (cerebrovascular disease), and chronic obstructive pulmonary disease remain near the top of the cause of death lists for 1990 and 2015.

These trends are hallmarks of an aging population in the midst of epidemiological transition. Surviving until age 5 greatly decreases a person’s chances of dying from a communicable disease and therefore increases their chances of living into adulthood. And people who survive into adulthood tend to die from diseases like ischemic heart disease and stroke – thus their continuing high rankings on cause of death lists. It is also clear that several non-communicable diseases which have long been associated with populations in more developed countries, such as diabetes and kidney disease, are causing an increasing number of deaths.

These changes in the leading causes of death do not take into account the amount of life lost. When examining the list of leading causes of YLLs in 1990 and 2015, it is clear that communicable diseases and neonatal disorders still exact a heavy toll on human health (see Figure 13). Along with road injuries, such causes

Figure 12
Causes of death, global, 1990–2015



of death accounted for seven of the leading 10 causes of YLLs in 2015. Because these health problems tend to impact younger people (unlike non-communicable diseases, which are more likely to affect adults), the total amount of lost life they cause is immense.

Non-communicable diseases remain the most common causes of disabilities. The lists of leading causes of YLDs in 1990 and 2015 changed far less than that of YLLs. The leading 10 causes of YLDs in each year include only one change over 25 years: oral disorders moved into the 10th spot on the list and asthma dropped from 10th to 11th (see Figure 14). The world made little progress in addressing the non-communicable causes of disability from 1990 to 2015.

Figure 13
Causes of YLLs, global, 1990-2015

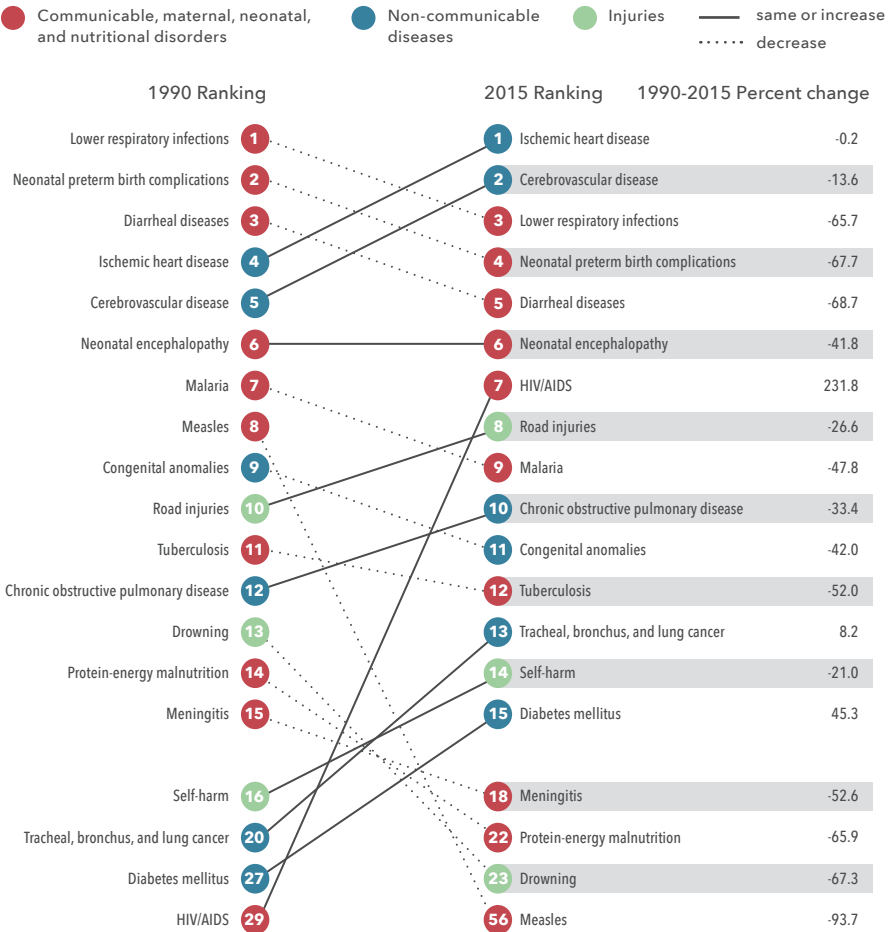
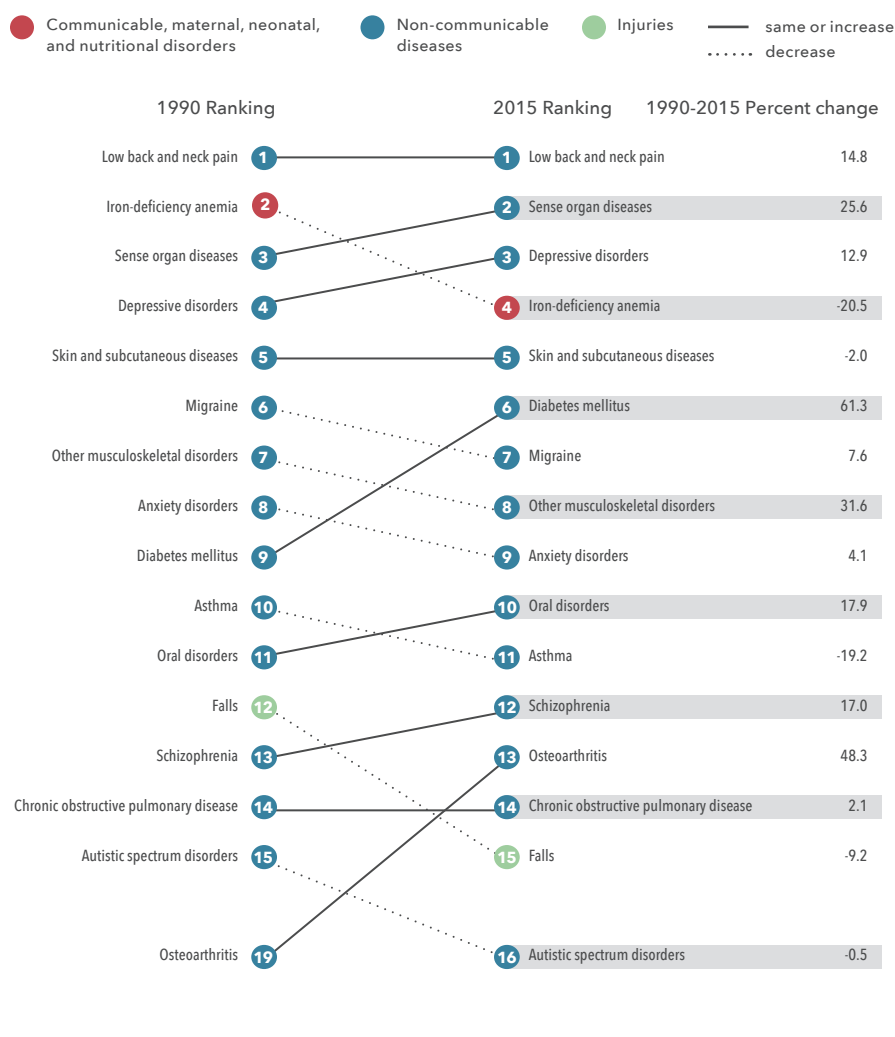
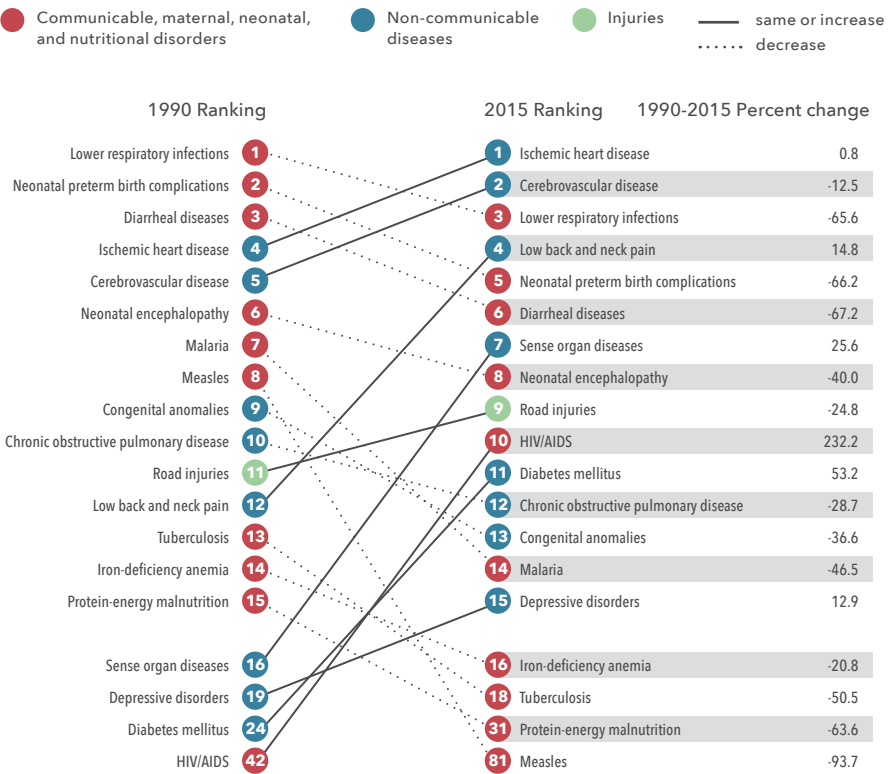


Figure 14
Causes of YLDs, global, 1990–2015



Considering the total burden of disease, as expressed in DALY rates, also shows the impact of non-communicable diseases. The role played by communicable, maternal, neonatal, and nutritional diseases in the leading causes of DALYs declined between 1990 and 2015 (see Figure 15). Lower respiratory infections, neonatal preterm birth complications, and diarrheal diseases – the three leading causes of DALYs in 1990 – fell to causes three, five, and six, respectively, in 2015. Many communicable diseases showed sharper declines. By contrast, the relative rankings of non-communicable disease and injury DALYs increased from 1990 to 2015, with ischemic heart disease and cerebrovascular disease occupying the first and second spots in the 2015 list.

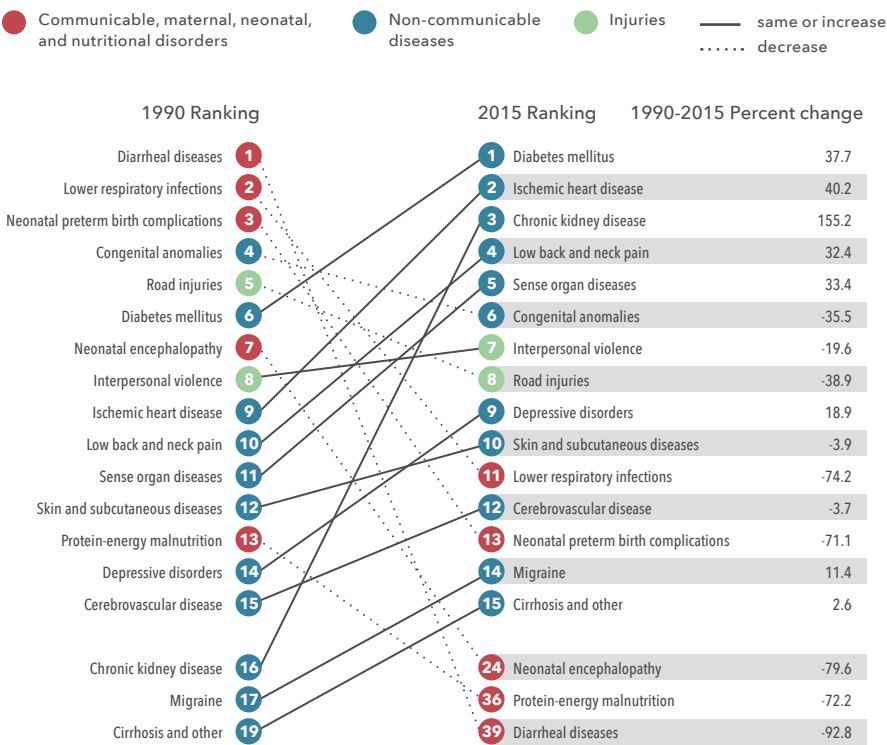
Figure 15
Causes of DALYs, global, 1990–2015



While taking a wide view of health problems can be illuminating, this view obscures variations at the local level. For that reason, GBD 2015 includes more sub-national data than any previous iteration of the project. One country with subnational data in the GBD dataset is Mexico. Mexico represents both the shift toward non-communicable diseases underway in 2015 and the potential utility of using subnational data to examine health trends.

Figure 16 shows the national-level picture of causes of DALYs in Mexico in 1990 and 2015. Note the distinct downward trend in communicable and neonatal causes. Between 1990 and 2015, such causes of disease fell from the top three spots in Mexico’s DALYs and out of the top 10 entirely. This represents a major achievement in population health, meaning that more newborns are thriving in the early weeks of life and more people are being saved from deaths by infectious disease. Note as well the accompanying rise in non-communicable diseases such as diabetes, ischemic heart disease, and chronic kidney disease. These shifts are characteristic of a country which has, like Mexico during the past 25 years, risen into the high-middle SDI quintile.

Figure 16
Causes of DALYs, Mexico, 1990–2015



Subnational data can be used to indicate where countries have health problems that need to be addressed. In many places in Mexico, diabetes has led to increasingly higher rates of early death and disability. Mapping the subnational rates of change in DALYs due to diabetes in Mexico between 1990 and 2015 (Figure 17) indicates that the burden of diabetes is rising most quickly in a few Mexican states: Quintana Roo, Tabasco, and Chiapas. Subnational health estimates like these can help allocate funding effectively, as when the Mexican government incorporated subnational GBD data into the Mexican national health plan that determined state health spending levels.

Subnational health estimates can also highlight success stories. Figure 18 depicts two maps, one from 1990 and one from 2015, that show the annual mortality rate due to diarrheal diseases for children under 5 years old by state. In 1990, children in the southern states of Chiapas, Guerrero, Oaxaca, and Puebla experienced the highest mortality rates due to diarrheal disease in Mexico, with Chiapas having the highest rate (354 deaths per 100,000). But the maps make clear just how far those states have come in preventing such deaths (Chiapas’s 2015 estimate is 29

Figure 17
DALYs due to diabetes, Mexico, annual percentage change 1990–2015

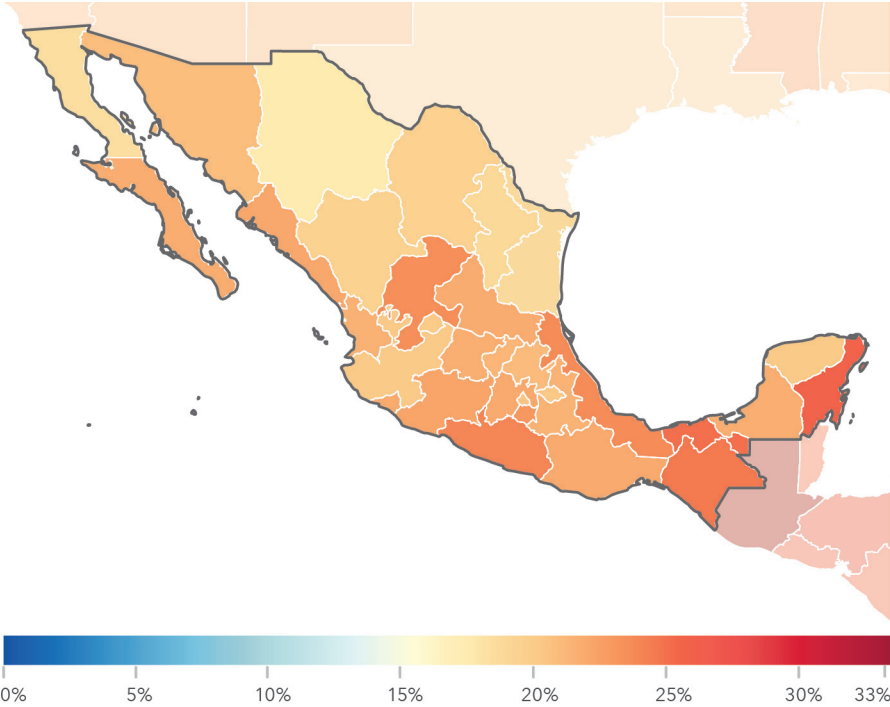
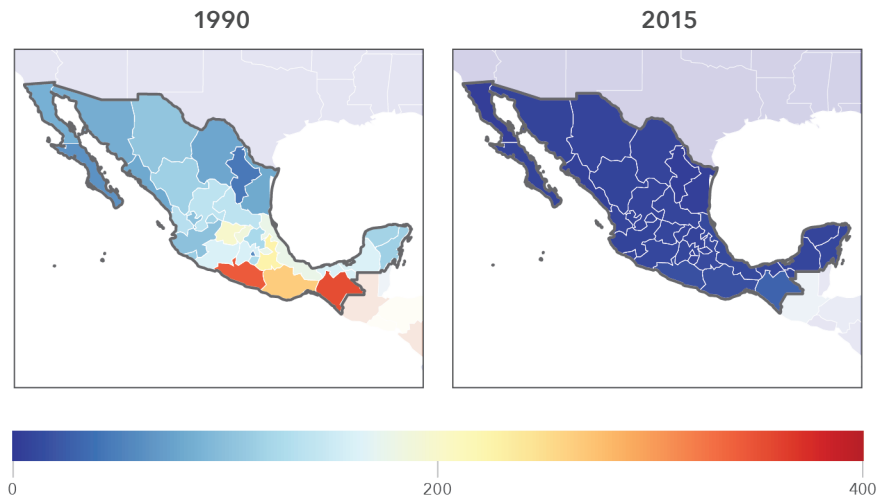


Figure 18
Mortality rate due to diarrheal diseases, Mexico, ages 0–5, 1990 versus 2015



deaths per 100,000). Successes like this are behind the decline in global YLLs and DALYs attributable to diarrheal diseases as seen in Figures 13 and 15. These three southern Mexican states also exemplify one key aspect of the epidemiological transition: fewer children dying from diarrheal diseases before their fifth birthdays and, therefore, more children likely to survive into adulthood.

Results in addressing non-communicable diseases are mixed

From 1990 to 2015, life expectancy at birth and the average population age have increased globally. The world’s population is also increasing, prompting an increase in the absolute burden of non-communicable diseases that tend to affect older people (ischemic heart disease, stroke, cancers, chronic obstructive pulmonary disease, diabetes, and others). The age-standardized DALY rate due to non-communicable diseases in general has been declining, however, as depicted in Figure 19. It is likely that part of this decline is due to the availability of better treatment and prevention for a subset of non-communicable diseases, such as cardiovascular diseases.

That we are getting better at treating and preventing some non-communicable diseases, while not improving the burden of others, is evident when examining how the health of females has changed from 1990 to 2015. Figure 20 shows the rate of

Figure 19

Age-standardized DALYS per 100,000 due to non-communicable diseases by SDI quintile, 1990–2015

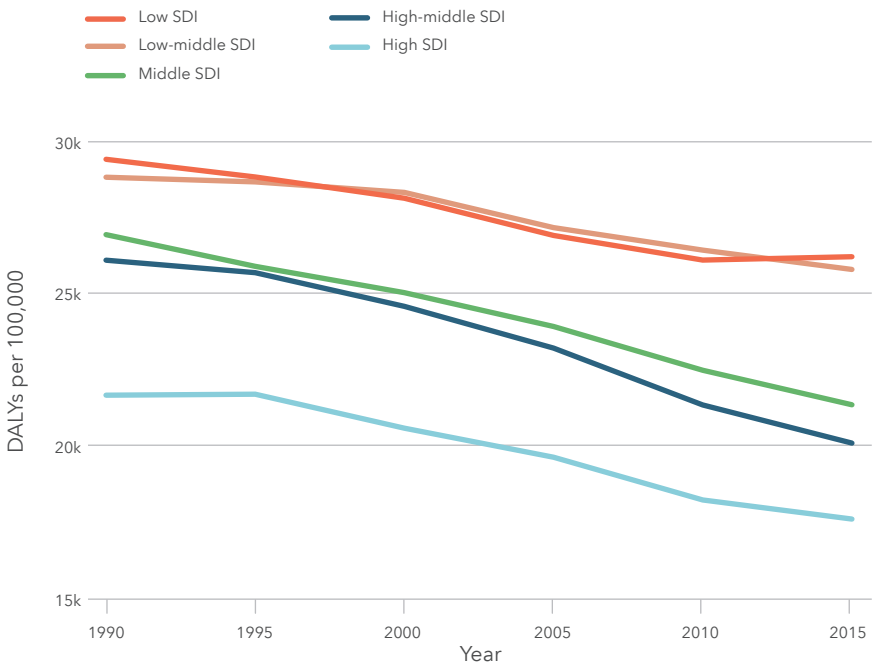
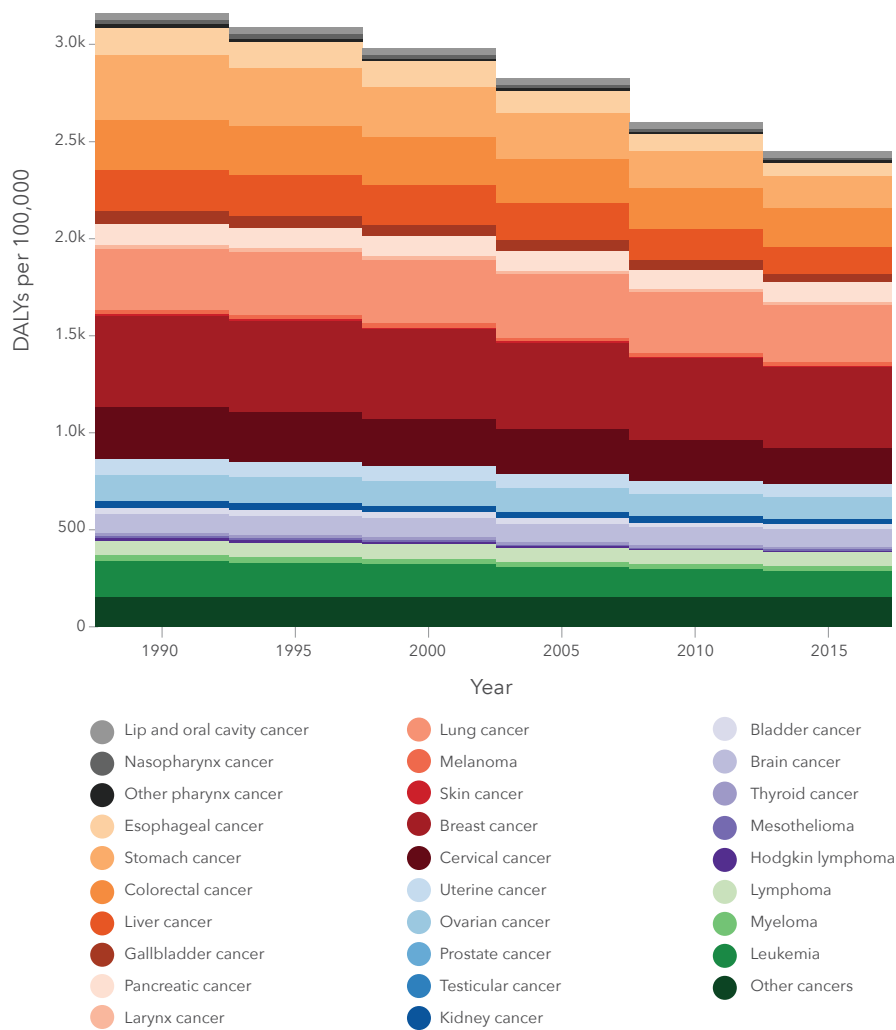


Figure 20
 Age-standardized DALYs per 100,000 due to cancers, females, 1990–2015

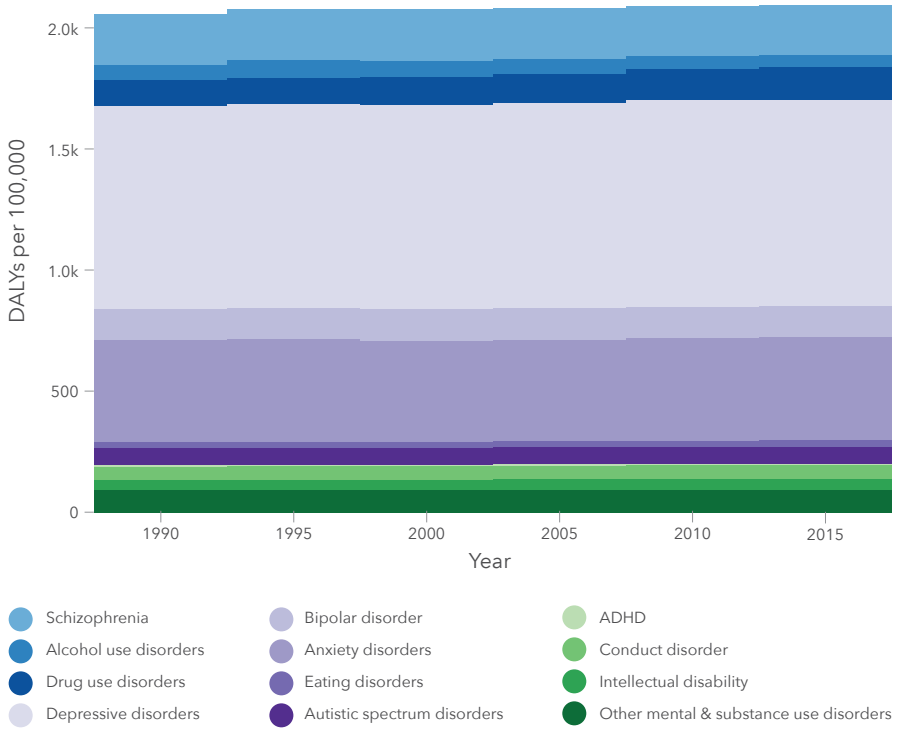


DALYs among females attributable to cancer. In general, DALYs due to cancer have declined, but the rates of decline are particularly fast for a few types of cancer, such as stomach, liver, and cervical cancer. At the same time that cancers in general, and some cancers in particular, show dropping DALY rates, the burden imposed by mental health and substance use disorders (Figure 21) during the same period has been flat or rising.

An aging world population portends a future in which non-communicable diseases will demand a great amount of attention and resources. Growing disease burden presents a challenge to health systems around the world. Those health

Figure 21

Age-standardized DALYs per 100,000 due to mental health and substance use disorders, females, 1990-2015



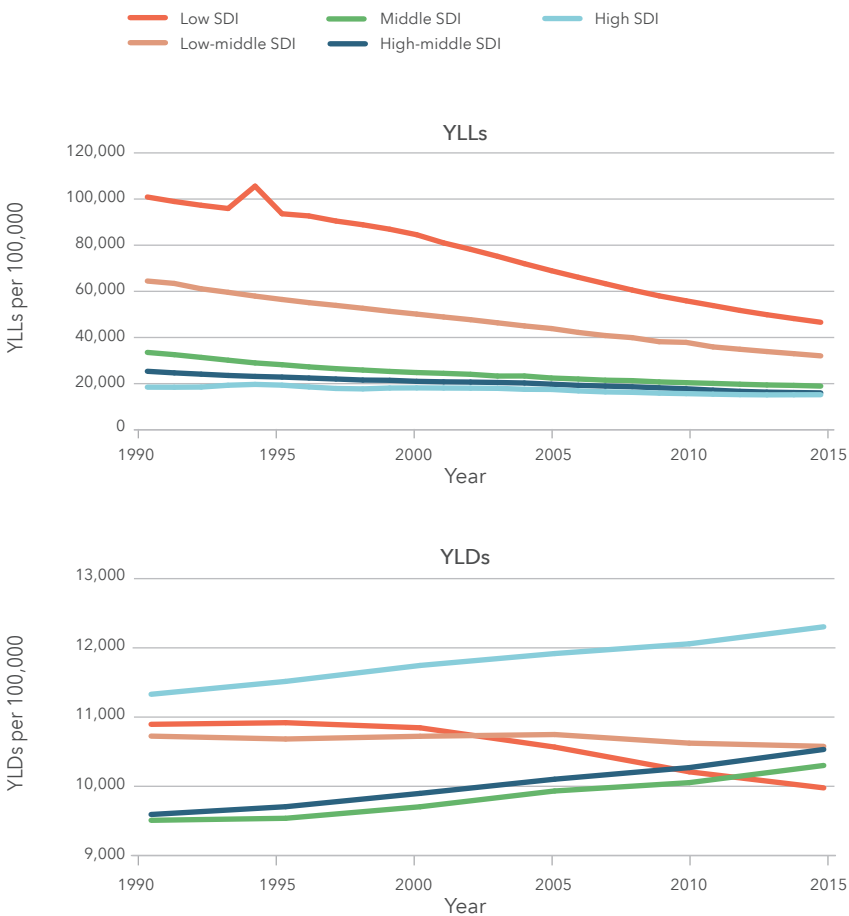
systems will need to take care of an increasing number of people whose aggregated health problems will tax those systems considerably.

Years spent living with disability are rising in many countries

The increasing life expectancy of the world's population is a profound epidemiological achievement and a transition to be celebrated, but it has been attenuated by an accompanying increase in time spent living with disability. Between 1990 and 2015, the portion of DALYs attributable to YLDs has shifted upward.

It should be noted, however, that this trend is partly dependent on development: while countries in every SDI quintile experienced a drop from 1990 to 2015 in the rate of years lost to premature death by their populations, the picture for years lost to disability was more nuanced. As shown in Figure 22, when breaking down YLDs from 1990 to 2015 by SDI quintile, we can see that middle- to high-SDI countries experienced increases in their rates of disability, but that YLD rates in the low-middle quintile of countries remained steady and those in the low quintile of SDI fell substantially.

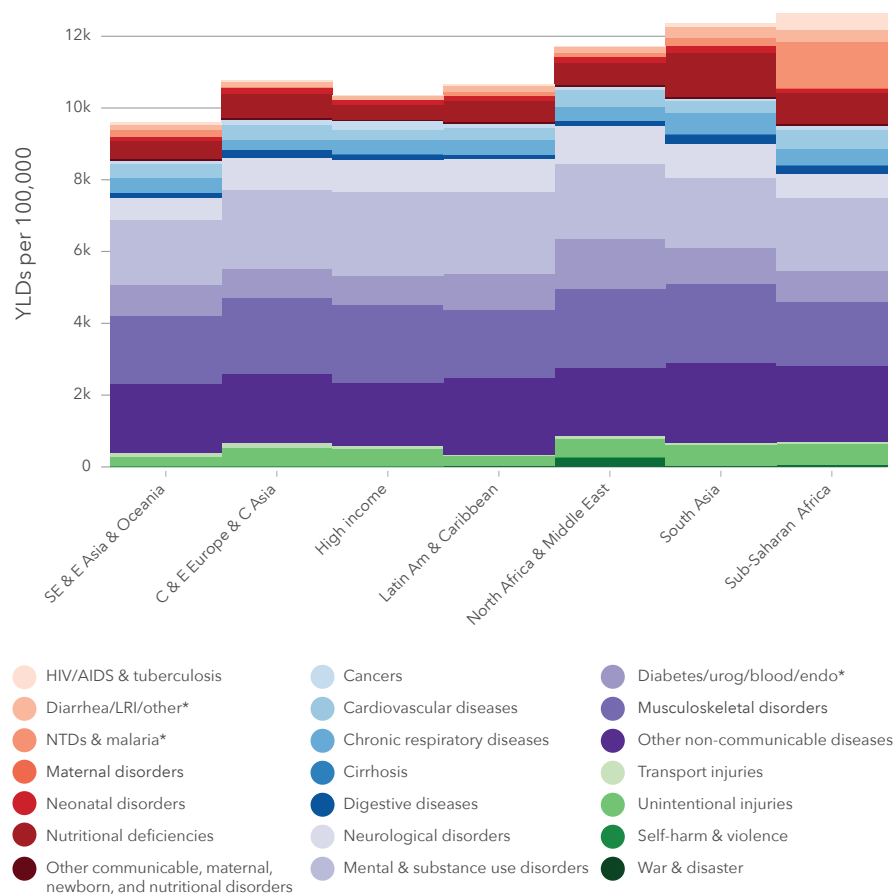
Figure 22
YLLs and YLDs by SDI quintile, 1990–2015



That does not mean, however, that YLDs are just a problem of higher-SDI countries. Figure 23 shows the 2015 YLD rates of the GBD super-regions. Note that, despite the decline in YLD rates in low-SDI countries from 1990 to 2015, YLD rates in places populated largely by low- and low-middle-SDI countries (sub-Saharan Africa and South Asia, for example) remain higher than those in other areas. The causes of YLDs differ among super-regions as well. For example, the YLD burden due to malaria and NTDs is far higher in sub-Saharan Africa than in other regions. Nutritional deficiencies cause the greatest YLD burden in South Asia and sub-Saharan Africa. On the other end of the spectrum, countries with the world’s lowest rates of YLDs are found in the Southeast Asia, East Asia, and Oceania super-region.

Figure 23

Age-standardized YLDs per 100,000, by region and cause, 2015

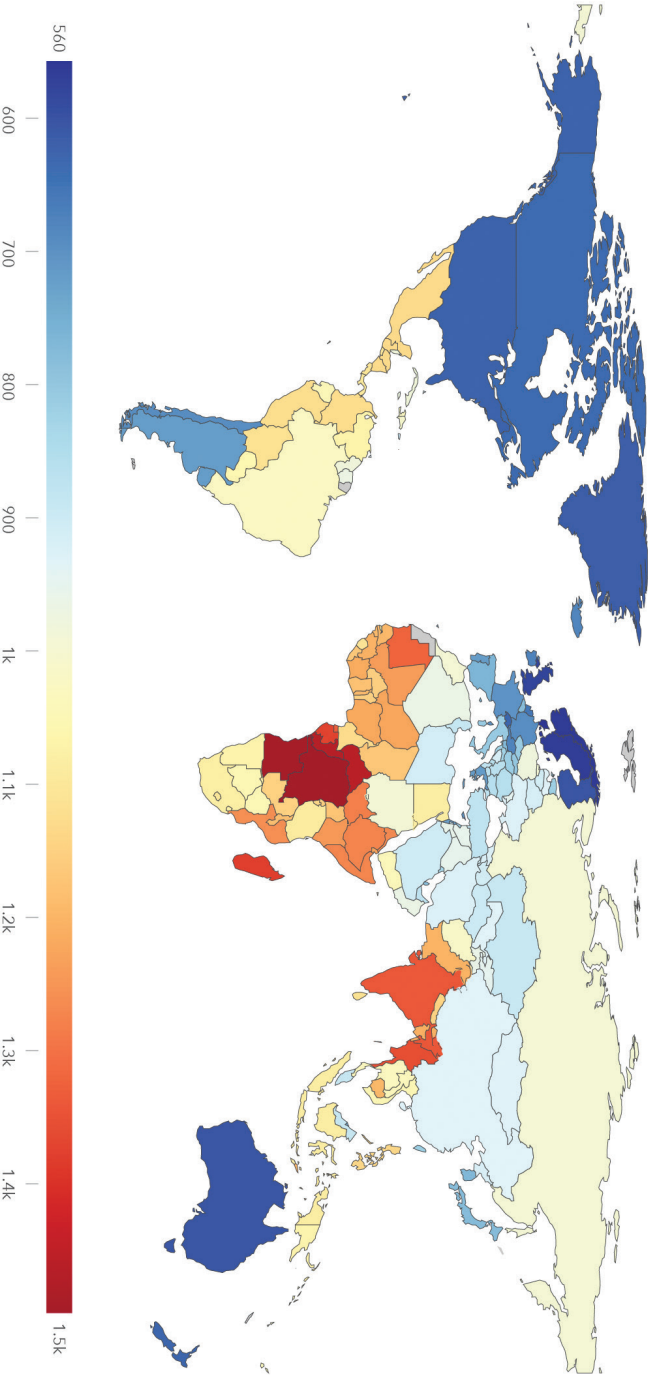


*LRI = lower respiratory infections, NTDs = neglected tropical diseases, urog = urogenital diseases, endo = endocrinological disorders

Communicable diseases are far from the only drivers of high YLD rates in low-SDI countries. Non-communicable health problems take their toll in less developed countries, just as they do in more developed ones. Consider, for instance, blindness and deafness – the second-leading cause (“sense organ diseases”) of YLDs in 2015. Figure 24 shows that, far from being a problem mostly for high-SDI countries, disability due to vision and hearing loss is most severe in sub-Saharan Africa and South Asia. Southeast Asia, Oceania, and parts of Latin America also face considerable burdens from vision and hearing loss. While time spent living with disability tends to increase as populations age and countries develop, disability is by no means only a problem of more developed countries.

Figure 24

Age-standardized YLDs per 100,000 due to sense organ diseases, 2015



Risk factor analysis reveals both hazards and opportunities

The epidemiological transition has resulted in changes in the disease burden borne by people, but it has also altered the composition of the risk factors that drive disease burden around the world. As that composition continues to change, health policymakers will need to adjust their efforts in order to address present and future burdens of disease. To aid this effort, previous versions of the GBD study have analyzed the risk factors that contribute to disease burden. Those efforts have engendered controversy, comment, and collaboration that have improved methods of assessing exposure to risks and measuring their contribution to disease burden.

While exposure to some risk factors declines as SDI increases, exposure to other risks increases. Over the past 25 years, many low-SDI countries have decreased exposure to risk factors such as unsafe sanitation and water, and reduced the burden of disease attributable to these risks. At the same time, exposure to other risk factors tends to increase with development, such as high body mass index, which is an indicator for obesity/overweight, high fasting plasma glucose, also known as high blood sugar, and drug use. One of the big questions for population health during the coming decades is whether middle- to high-SDI countries can succeed in reducing exposure to those risk factors going forward.

By focusing on risk factors, the GBD study points to the potentially modifiable hazards in our world – levels of indoor air pollution, for instance, or poor diets – that could be used to improve human health over the coming decades.

From a population health standpoint, the most pressing targets for intervention are those risk factors that cause the largest burden of disease and are increasing rapidly. Those risk factors include high body mass index, high fasting plasma glucose, ambient air pollution, and drug use.

Summary exposure value and attributable burden

The GBD 2015 risk factor analysis consists of two different sets of estimates: those for attributable burden of disease and those for the summary exposure value (SEV) of certain behavioral, environmental/occupational, and metabolic risk factors. Attributable burden is the share of the burden of a disease that can be estimated to occur due to exposure to a particular risk factor. It is expressed in mortality rates, YLLs, YLDs, or DALYs – just like causes of disease or injury in the GBD study.

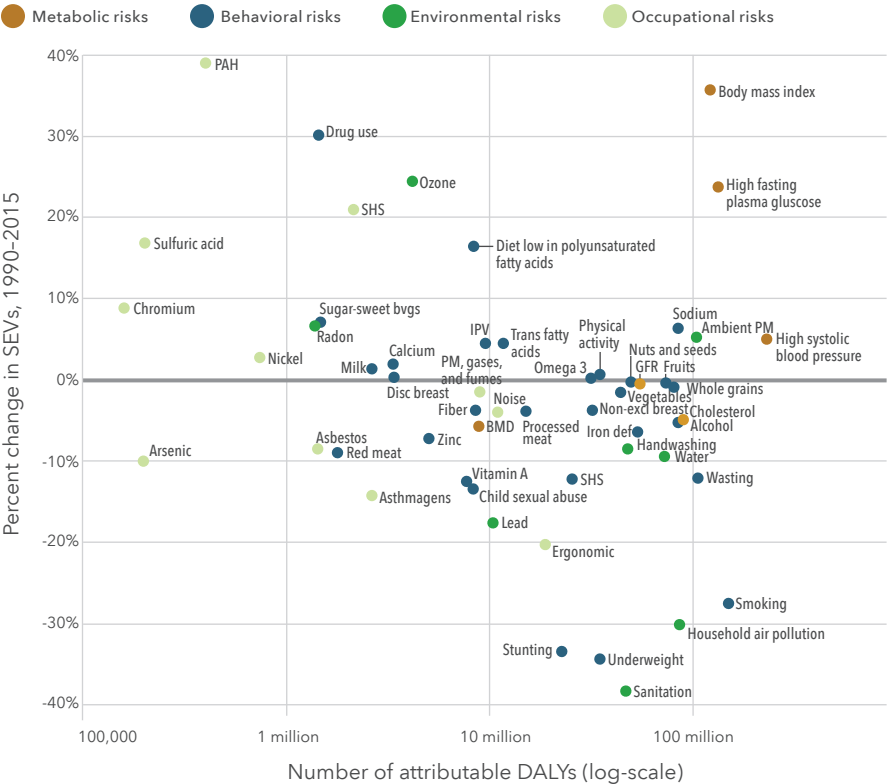
Summary exposure value is different. It is an estimate of exposure to risk factors that takes into account the severity of exposure and the size of the population exposed to it. Instead of classifying exposure to a risk as either present or not present, SEV allows for the estimation of risk exposures that are continuous or happen at different times in different amounts. This is advantageous for estimating population exposure to risk factors because in reality people are exposed to many risk factors intermittently or continuously, rather than all at once or not at all. The SEV metric also takes into account the severity of exposure to a risk factor, since some risk factors are more likely than others to lead to health problems.

These risk factors appear toward the upper right side of Figure 25, which plots risk factors on an axis that combines those risks' overall burden on human health as of 2015 (the x-axis) and their change in exposure level from 1990 to 2015 (the y-axis). Thus, risk factors on the left of the chart have a smaller attributable DALY burden and those on the right a larger one.

Risk factors at the top of the chart have increased markedly in exposure from 1990 to 2015, while those on the bottom have declined in exposure during that time. Most of the risk factors in the top half of Figure 25 are those associated with older populations living in more developed countries. Exposure levels and attributable burdens for those risks tend to rise as countries move upward in the spectrum of development. Many of the risk factors in the bottom half of the chart are associated with younger populations living in less developed countries, and exposure to them has declined as countries have become more developed.

The risk factors that contribute to the greatest burden of disease are also important priorities for improving population health. For example, even though exposure to tobacco smoking has declined, Figure 25 shows that it is one of the top drivers of burden worldwide. Risks like high systolic blood pressure (high blood

Figure 25
Risk factors by attributable DALYs, 2015, and percent change in summary exposure value, 1990–2015



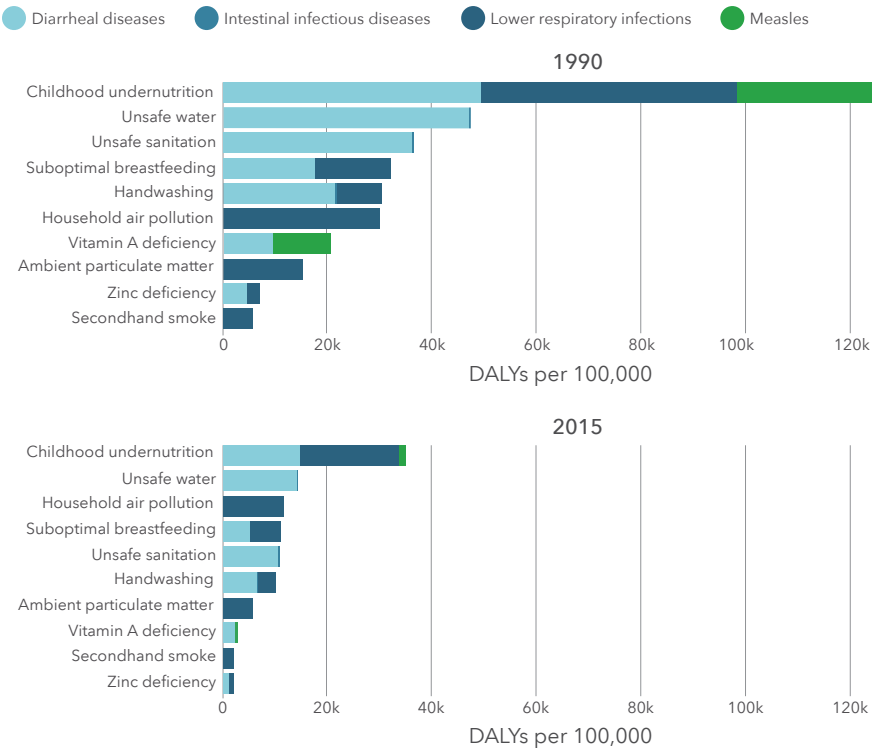
pressure), ambient particulate matter (air pollution), and diets high in sodium continue to cause appreciable disease burdens, even though their exposure levels have not risen nearly as quickly.

Figure 25 indicates that public health efforts to combat risk factors linked to non-communicable diseases, with the exception of tobacco smoking, have largely failed. Identifying strategies that actually work to reduce these risk factors is urgently needed. Health care – not public health interventions – is likely responsible for global reductions in death rates from non-communicable diseases such as ischemic heart disease and stroke.

Another main finding is that the dramatic success in reducing the global burden of pneumonia in children has been driven by reduction in exposure to different risk factors that contribute to these diseases, such as unsafe sanitation; household air pollution; childhood underweight, stunting, and wasting; unsafe water; and no handwashing with soap.

The bulk of success in reduction of exposure and attributable burden of risk factors from 1990 to 2015 came in lower-SDI countries. Figure 26 shows the risk-attributable burden of DALYs for four common causes for children under 5 in

Figure 26
Attributable burden of DALYs per 100,000 for diarrheal diseases, intestinal infectious diseases, lower respiratory infections, and measles, ages 0–5, low-SDI quintile, 1990 versus 2015

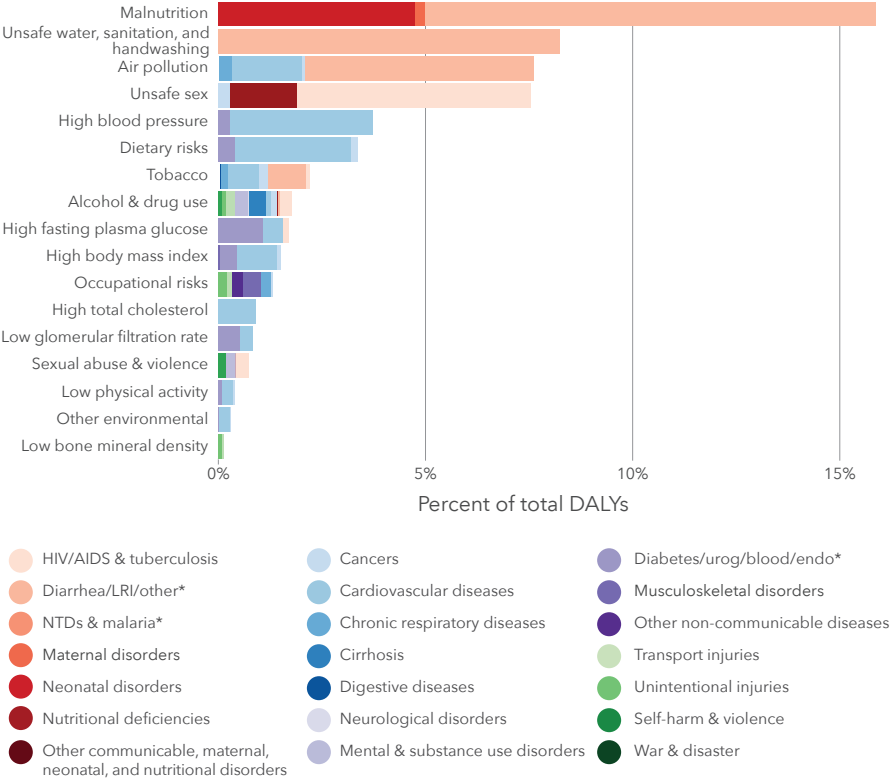


low-SDI countries in 1990 and 2015. Note the substantial and widespread improvement over time, concentrated in risk factors that contribute to diarrheal and lower respiratory diseases.

Figure 25 also makes clear just how difficult it has proved to reduce risk exposure levels as countries increase in SDI level. The past 25 years have seen marked efforts to improve population health by reducing exposure to behavioral risk factors, but exposure levels to risks such as low intake of whole grains and fruits and low level of physical activity have remained stubbornly flat. The only big risk reduction achieved by middle- to high-SDI countries during that time was in smoking. Declines in smoking exposure in high-middle- and high-SDI countries have driven the global decline observed in Figure 25; smoking exposure was flat in low- and low-middle-SDI countries and declined slightly in middle-SDI countries.

The profiles of health risks faced by people in countries with higher and lower SDIs differ. Figure 27 and Figure 28 support that point by attributing the proportion of disease burden in low- and high-SDI countries to risk factor groups. High systolic blood pressure is a risk shared by both country groupings but is responsible

Figure 27
Percentage of attributable burden of DALYs by risk factor, low-SDI quintile, 2015



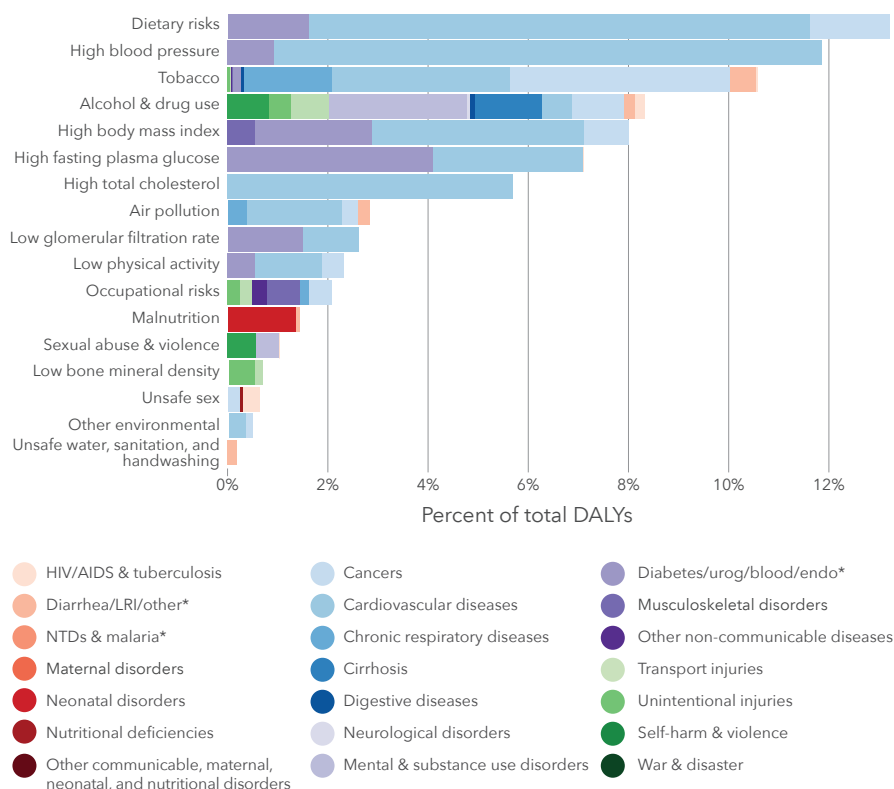
*LRI = lower respiratory infections, NTDs = neglected tropical diseases, urog = urogenital diseases, endo = endocrinological disorders

for a far greater disease burden in high-SDI countries. Unsafe water, sanitation, and handwashing, by contrast, is a miniscule problem in the high-SDI world but a substantial contributor to diarrheal and other infectious diseases in low-SDI countries. Air pollution is a leading risk factor in both groups of countries, but the burden linked to that risk differs: in high-SDI countries, air pollution contributes mostly to cardiovascular disease, chronic respiratory diseases, and cancers, whereas in low-SDI countries air pollution causes the most DALYs in infectious disease (specifically, lower respiratory infections).

Taken together, Figure 25 through Figure 28 illustrate both improvements and causes for continued concern. The considerable effort expended to improve environmental and behavioral risks related to diarrheal and lower respiratory diseases in low- and low-middle-SDI countries since 1990 has succeeded in lowering exposure and attributable burden, but the level of burden attributed to those risks remains much higher in low-SDI countries than high ones. Worse, the victims of diseases associated with those risks are disproportionately young children, resulting in an immense number of YLLs in low-SDI countries.

Figure 28

Percentage of attributable burden of DALYs by risk factor, high-SDI quintile, 2015



*LRI = lower respiratory infections, NTDs = neglected tropical diseases, urog = urogenital diseases, endo = endocrinological disorders

In middle- and high-SDI countries, meanwhile, children tend not to die from diseases attributable to exposure to environmental risks, but risk exposure still exacts a heavy toll on population health. In higher-SDI countries, risks with the highest attributable burden tend to be behavioral (especially dietary) and metabolic. The drastic increases in high body mass index, high fasting plasma glucose, and drug use represent, to some extent, both an expected tendency of increasing worldwide levels of development and a failure of the world's public health systems. It may also be the case that, as more countries around the world undergo epidemiological transition, the risks associated with life in countries that rank higher in SDI – poor diets, obesity, and high blood pressure – will become more prominent.

Given the difficulty of addressing risk factors via behavioral and environmental change, it may be that treatment of health problems linked to risks will remain the most straightforward way of addressing risk exposure for some time to come. Consider the example of HIV/AIDS, detailed in Figure 11. The decline in DALYs due to HIV/AIDS from 2005 to 2015 was not due primarily to changes in exposure to unsafe sex. Rather, it was the widespread availability of antiretroviral therapy that caused the decline.

GBD 2015 can help measure progress toward the United Nations Sustainable Development Goals

One of the key ways in which this report has proposed to evaluate the success of countries attempting to improve their population health and manage the ramifications of epidemiological transition is by comparing countries' observed progress versus that expected based on SDI. But this is not the only way to assess the relationship between health performance and development. The United Nations, for example, has set benchmark goals for health and development, first in the form of the Millennium Development Goals (MDGs) for 2000 to 2015 and then in the Sustainable Development Goals (SDGs) for 2015 to 2030.²³ These goals are designed to spur improvements in health, equity, and overall well-being in countries at all levels of development.

Health plays a huge role in the SDGs. Of the 17 SDGs, 11 contain targets related to health. One SDG is focused entirely on health: Goal three is to “ensure healthy lives and promote wellbeing for all at all ages.” Within each goal are targets and indicators that will be used to judge success, such as “halve the number of global deaths and injuries from road traffic accidents” by 2020, and “by 2030, reduce the global maternal mortality ratio to less than 70 per 100,000 live births.” Just measuring the progress made toward meeting the health-related SDGs is an enormous task – one that will require coordinated action across institutions and governments around the world. In this respect, the GBD 2015 study offers to the SDG effort independent measurements of health and development indicators that can be used to assess progress toward the goals.

Of the health-related goals within the SDGs, GBD data are available to measure 33 of them. GBD researchers used these data to generate a baseline picture against which SDG progress can be measured.²⁴ As of the SDG era's beginning in 2015, there are many goals that have not yet been achieved by any country in the world, such as eliminating new HIV infections or intimate partner violence. The world has made significant progress on a few goals, such as reducing the maternal

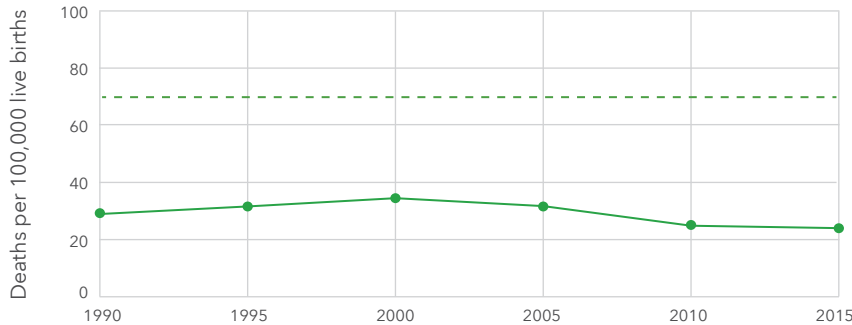
mortality ratio to 70 per 100,000 live births (achieved by 61% of countries) and reducing the neonatal mortality rate to 12 per 1,000 live births (58%).

Using GBD 2015 data, researchers generated indices of progress toward achievement of the health-related SDGs in 188 countries. In general, higher-SDI countries had higher SDG index values, indicating that they had already achieved more of the 2020 and 2030 SDG goals than had less developed countries. That pattern did not hold in every case, however, and it certainly did not hold for every indicator. Countries often displayed different achievement patterns for different indicators. Consider the case of Costa Rica, which sits precisely in the middle of health-related SDG achievement rankings. Figure 29 shows that Costa Rica has, in 2015, already achieved SDG 3.1.1 (reducing its maternal mortality ratio to below 70 deaths per 100,000 live births): Costa Rica’s 2015 maternal mortality ratio was 24 deaths per 100,000 live births. By contrast, Costa Rica has not yet achieved the part of SDG 2.2.1 calling for the elimination of malnutrition in children under 5, despite its steady improvement toward that goal.

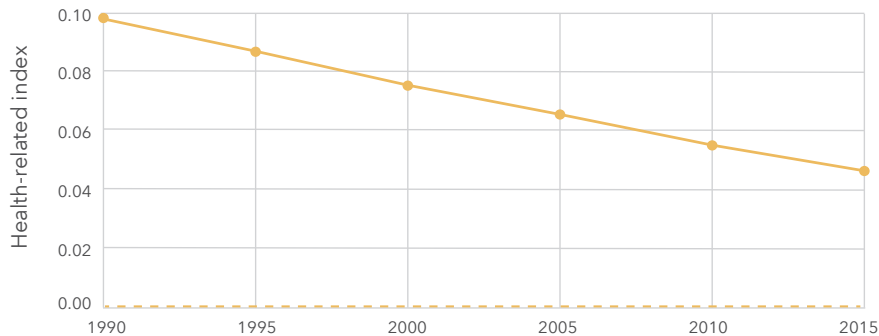
Figure 29
Status of Costa Rica regarding SDGs 3.1.1 (top) and 2.2.1 (bottom), 2015

----- SDG target

Indicator 3.1.1: Maternal mortality ratio (maternal deaths per 100,000 live births)



Indicator 2.2.1: Prevalence of stunting among children under 5 years of age



The researchers also evaluated progress toward health-related SDG goals that were part of the MDG effort versus those that were newly established by creating an index that ranked their achievement. Countries' index values for health-related SDG indicators that were shared with MDGs were generally higher than their scores for entirely new SDGs. For example Costa Rica's overall health-related SDG index value is 67. That score lies between its score for SDGs that were also MDGs (71) and those that were not (64). As with most of the world, Costa Rica is higher performing in longer-established, arguably less ambitious measures of population health.

As efforts to achieve the health-related SDGs go forward, GBD data will be a valuable resource. Benchmark data on many of the health-related SDGs will be compared with data collected in the coming years. Countries that make particularly fast progress toward the SDGs – particularly if that progress is faster than expected based on those countries' SDIs – could be examined closely to establish best practices that might be replicated in other countries striving toward meeting the SDGs.

Conclusion: GBD 2015 can inform future health policy

The benchmarking utility of GBD 2015 is not, of course, limited to evaluating SDG progress. The health estimates generated by GBD 2015 serve as benchmarks and data points in an ongoing study of population health covering the last 25 years.

The picture of world health in 2015 features a few key themes. First and foremost, the global population is in the midst of an epidemiological transition. Life expectancy is increasing around the world as more children live past the age of 5 and more mothers survive the childbirth process. Fewer people overall are dying from communicable and nutritional diseases.

That positive picture is complicated, though, by other aspects of the epidemiological transition. While they are living longer lives, people are still dying early, often from preventable causes, with non-communicable diseases claiming an increasing share of deaths around the world. Although progress in treating some of these non-communicable diseases, such as many cancers, has been steady, improvements in treatment have mostly succeeded in lengthening lives lived with non-communicable diseases instead of eliminating these diseases entirely.

There are a host of non-communicable diseases for which we have made very little progress in treatment or prevention. Diseases affecting mental and musculoskeletal health, for example, remain just as widespread and problematic as they were 25 years ago, contributing to increases in disability burden. As years lost to premature death have decreased, much of that time gained has been compromised by disability.

Increases in years lost to disability are especially disconcerting when considered in conjunction with exposure to risk factors. Many risk factors that contribute to disability – such as high body mass index, high blood sugar, and drug use – have risen sharply in exposure levels, which will likely increase disability burden in the future.

The assessment of global health is further complicated by development and equity. Even though some of the biggest improvements in health outcomes during the past 25 years have occurred in places with lower SDI levels, health is still a personal and social good that is distributed unequally. Life expectancy and other

health outcomes are markedly higher in more developed countries than in less developed ones. Equitable access to health continues to be, perhaps, the great health-related problem for the world.

Work left to be done and the questions left unanswered will fuel efforts on future editions of the GBD study. Increasing the amount of and access to quality data will be vital to improving health in the coming decades. Increasing the size and depth of the GBD collaborator network will aid in improving estimation methods and better leveraging the available health data. Ultimately, future GBD work will be directed toward the same goal that has sustained the Global Burden of Disease study in the past: putting better information into the hands of policy-makers in order to improve the quality and equity of world population health.

Methodological appendix

Completing the GBD 2015 study required pooling and analyzing an enormous amount of data using complex estimation methods. This section offers a brief overview of the GBD methodology. Full details of the GBD methods are publicly available per the stipulations of the GATHER standards. Methodological information may be found on the IHME website and in the academic papers announcing the GBD 2015 results, which are available free of charge on *The Lancet's* website:

- GBD 2015 Mortality and Causes of Death Collaborators. Global, regional, and national life expectancy, all-cause and cause-specific mortality for 249 causes of death, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet* 2016.
- GBD 2015 Maternal Mortality Collaborators. Global, regional, and national levels of maternal mortality, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet* 2016.
- GBD 2015 Child Mortality Collaborators. Global, regional, national, and selected subnational levels of stillbirths, neonatal, infant, and under-5 mortality, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet* 2016.
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- GBD 2015 Risk Factors Collaborators. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet* 2016.
- GBD 2015 SDG Collaborators. Measuring the health-related Sustainable Development Goals in 188 countries: A baseline analysis from the Global Burden of Disease Study 2015. *The Lancet* 2016.

An egalitarian approach to health estimation

The GBD methodology rests upon an egalitarian foundation for generating health estimates. When estimating the time lost to health problems around the world, the starting point against which that estimate must be measured is life expectancy. The GBD uses as the starting point for its estimations the highest life expectancy observed in the world by age and sex. In 2015, that standard life expectancy for a male aged 25 years old was 56.6 (or a lifespan of 81.6 years, observed in the country of Andorra); for a female aged 50 years old it was 39.1 (for a total of 89.1 years lived; also observed in Andorra). These age- and sex-dependent life expectancies form the foundation for calculating YLLs, YLDs, HALE, DALYs, and other GBD metrics.

Using a life expectancy tied not to location but to the longest lifespan achieved by people serves two main purposes. First, it acknowledges that although geography holds an outsized influence on life expectancy and health outcomes, it ought not to, and we must work to eliminate health disparity. Second, using a standard life expectancy sets a high bar for achievement in health improvement goals.

Generating the GBD 2015 estimates

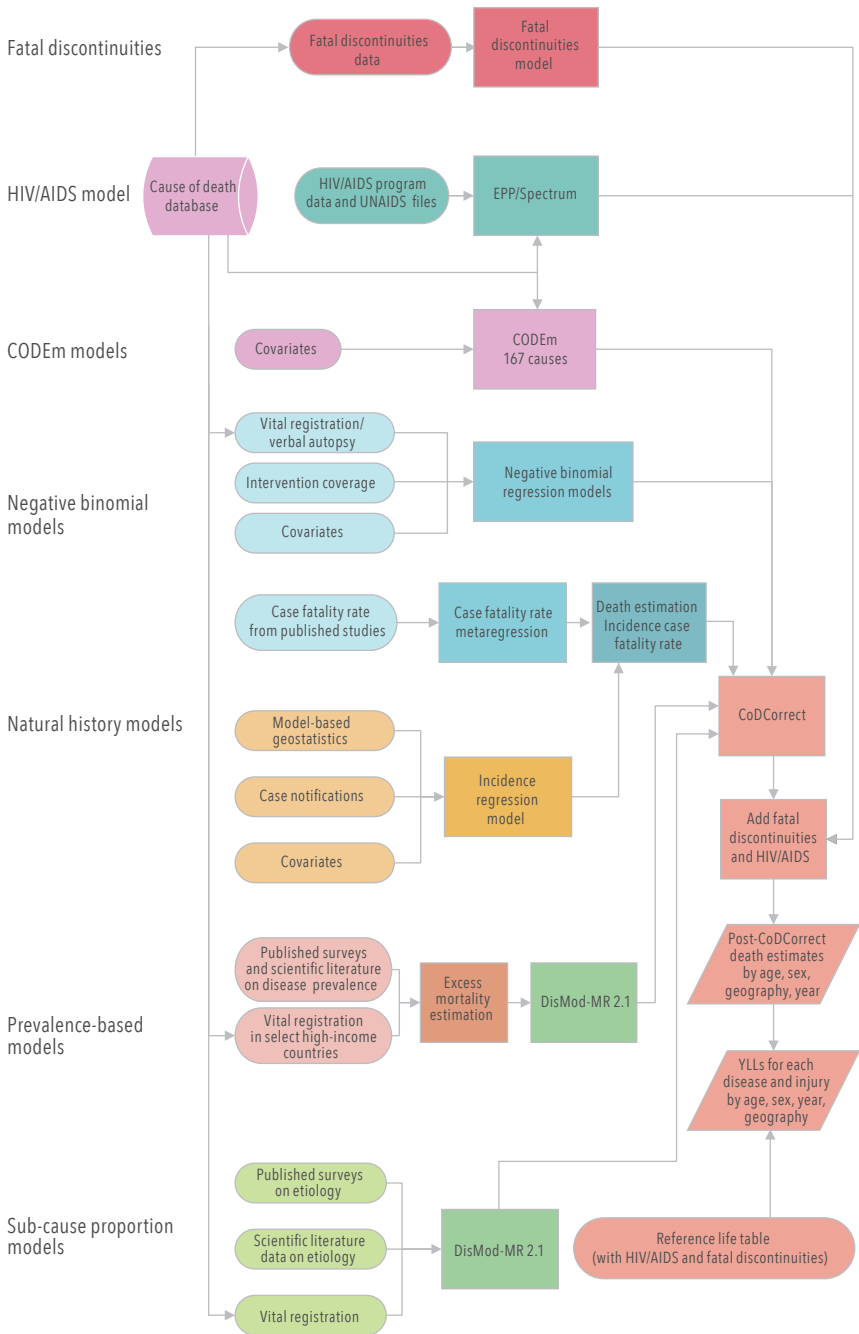
The GBD 2015 estimation process is highly interconnected. If new data are incorporated into one aspect of the analysis, the estimates that result from those new data may in turn affect other estimates within the system. When, for example, new data are added to the child mortality rate analysis, they affect the estimates of the number of deaths by age, sex, year, and country, which in turn affect cause of death estimation and the calculation of YLLs and DALYs. Figure 30 illustrates the development of the cause of death database, a tiny part of the previous example and, in turn, the overall GBD estimation process.

This appendix contains only brief descriptions of the key components of GBD 2015 estimation, but more detailed information – including more flowcharts detailing the GBD estimation process – is available in the GBD 2015 articles published in *The Lancet*, which are publicly available on the websites of *The Lancet* and IHME. Making such methodological information available is a key part of the GATHER guidelines and aids experts in evaluating the GBD estimation process and results.

Data sources

The dataset used for the GBD estimates is immense. GBD researchers compiled all available data on causes of death, disease, and injuries in 188 countries and seven nonsovereign territories. The data used just for the generation of YLL estimates, for example, are drawn from 43,134 unique sources. Information from many different sources fed into the overall dataset. In estimating causes of death, the GBD study used data derived from vital registration systems, mortality surveillance systems, censuses, surveys, hospital records, police records, mortuaries, and verbal autopsies. (Verbal autopsies are surveys that collect information from individuals familiar with the deceased about the signs and symptoms the person had prior to death, allowing researchers to deduce how that person died.) GBD researchers then completed a multi-step data cleaning process. This involved tasks such as removing erroneous codes, applying statistical techniques to compensate for biases in the

Figure 30
Analytical flowchart for GBD 2015 cause of death database development



data sources, standardizing coding for causes of death problems, and reassigning deaths from incorrect causes to correct ones. The end result was a huge, standardized dataset.

Mortality

Estimating mortality by cause allows for the further estimation of YLLs, YLDs, DALYs, and so on. Therefore, mortality estimation is one of the first major steps in the GBD calculations. After addressing data-quality issues, researchers used a variety of statistical models to determine the number of deaths from each cause. This approach, which uses the CODEm (Cause of Death Ensemble model), was designed based on statistical techniques called “ensemble modeling” and was used for the vast majority of cause-specific mortality estimates. To ensure that the number of deaths from each cause did not exceed the total number of deaths estimated within GBD, researchers applied a correction technique named CoDCorrect. This technique makes certain that estimates of the number of deaths from each cause do not add up to more than 100% of deaths in a given year.

YLLs

After producing estimates of the number of deaths from each of the fatal outcomes included in the GBD cause list, researchers then calculated years of life lost to premature death, or YLLs, for each cause of death. This calculation depends on the life expectancy standard discussed above, in which any death from a particular cause is attributed YLLs equal to the highest observed life expectancy minus the age of death, or $YLL = (\text{highest observed life expectancy for age-of-death cohort}) - (\text{age at death})$. The YLL calculation, accordingly, places more weight on causes of death that occur in younger age groups. The YLLs attributed to a single death due to malaria are likely to be much higher than the YLLs for a single death due to ischemic heart disease, since malaria tends to kill young children and ischemic heart disease primarily affects older adults.

YLDs

The estimation of YLDs consists of three main steps: establishing the prevalence and incidence of causes and sequelae (health states caused by a disease, for example, the blindness that can be caused by diabetes) related to disability, assigning levels of severity to those disabilities, and combining those two things into one comprehensive measure of nonfatal health loss.

Researchers collected data from government reports of cases of infectious diseases, data from population-based disease registries for conditions such as cancers and chronic kidney diseases, antenatal clinic data, hospital discharge data, and many other sources. They then used those data, along with tools such as DisMod-MR 2.1 (Disease Modeling-Metaregression, a Bayesian metaregression tool developed for GBD 2010 and improved for GBD 2015), to generate estimates of the prevalence and incidence of disability-causing sequelae.

To assign levels of severity to the disability sequelae, researchers used data from an open-access internet survey and household surveys in Bangladesh, Peru, Tanzania,

Indonesia, the United States, the Netherlands, Italy, Sweden, and Hungary, which were undertaken between 2009 and 2013. Survey respondents were asked to rate the severity of different health states. The results were similar across all surveys despite cultural and socioeconomic differences. Respondents consistently placed health states such as mild hearing loss and long-term treated fractures at the low end of the severity scale, while they ranked acute schizophrenia and severe multiple sclerosis at the high end of the scale. The researchers used these survey results to create disability weights, which are coefficients of severity on a scale of 0 to 1 attributed to each disability. Multiplying a disability weight by time results in a “discounted” amount of time that captures the years spent living with that disability.

After estimating the prevalence of various disabilities and establishing the relative severity of those disabilities, GBD researchers could combine the two, calculating the overall amount of time spent living with disability. Summing the time lost to specific disabilities can be used to calculate time living with a specific disease that causes multiple disabilities, time spent living with disability by certain populations or age groups, or the overall burden of disability so that it might be compared to the overall burden of premature mortality.

DALYs

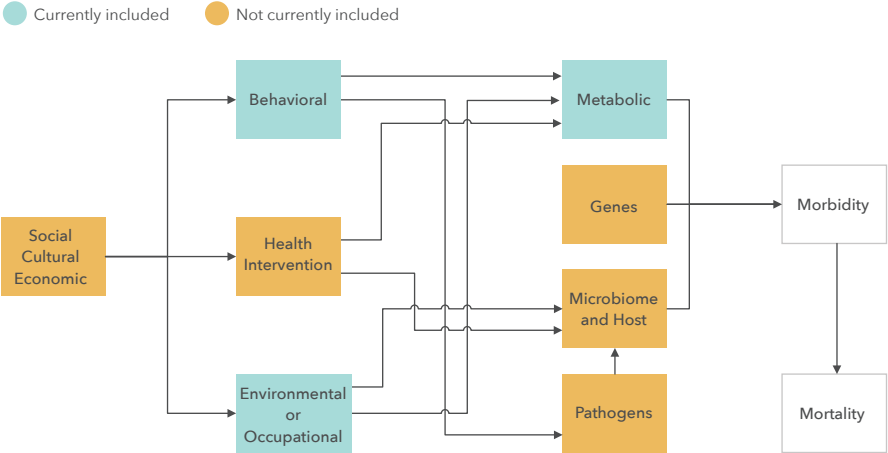
With YLLs and YLDs estimated, the calculation of DALYs is relatively simple: YLLs and YLDs by cause were summed for each geographical location, age group, sex, and year. DALYs, therefore, contain within them the features inherent in both YLLs and YLDs. For example, DALYs, like YLLs, weight the life lost to diseases affecting children more than that lost to diseases affecting older adults. The benefit to understanding population health derived from combining YLLs and YLDs into DALYs comes from the ability to make direct comparisons between diseases or injuries that are dissimilar in character or severity. DALYs offer, for example, a way to compare the population-level burden of colorectal cancer with that of low back and neck pain. DALYs also provide a way to portray the combined mortality and disability burden of a specific cause of disease or injury in one measure.

Risk factors

The comparative risk analysis in GBD 2015 consists of two separate pieces: the estimation of summary exposure value for risk factors and the estimation of disease burden attributable to risk factors. It should be noted that the GBD 2015 risk factor analysis does not include analyses of every health risk faced by people. Due to limitations in methodology and the availability of high-quality data, the GBD study focuses its risk analysis efforts on three risk categories for which methods and data currently allow credible analyses: behavioral, environmental or occupational, and metabolic risk factors. Figure 31 illustrates the interplay of risk categories affecting human health while highlighting those categories currently included in GBD analyses.

One key piece of the GBD 2015 risk factor analysis is summary exposure value, or SEV. SEV allows comparison between risk factors that incorporates both the range of severity of a risk and the population exposure within that range. The calculation of SEV starts by estimating the prevalence of exposure to a risk factor in

Figure 31
 Risk factors included and not included in GBD risk factor analyses



a population at each level of potential risk and weighting that prevalence according to the likelihood of that particular risk causing a health outcome. That weighted prevalence measure is then calculated repeatedly for each combination of risk and outcome pairing by age, sex, location, and year. The resulting estimates can then be summed across causes, years, and so on.

In order to estimate the disease burden attributable to different risk factors, GBD researchers compared the disease burden in a population exposed to a risk factor to the disease burden expected in a population with the lowest possible risk exposure. The difference between those numbers – the excess risk above the theoretical lowest risk scenario experienced by a population – was attributed by cause for each age, sex, location, and year in the study. Performing that estimation process required a number of complicated steps – steps that GBD researchers (and interested parties critiquing the GBD study) continue to debate, refine, and improve.

The attributable burden analysis began with a hierarchical list of risks that contribute to health outcomes. The structure of that list allows for the quantification of the amount of responsibility that any given risk has in causing any given health cause. That depended on extensive research into risk-outcome pairs, in which GBD researchers conducted reviews of existing research to establish the likelihood that a risk will cause a particular health outcome. The extent to which a particular risk is likely to cause a particular outcome is a key part of estimating attributable burden. Note that the attributable burden of all health risks adds up to far less than the total disease burden for any given population or year. The main reasons for this are methodological and epistemological: the practice of estimating attributable burden of health risks is a new and evolving field and one that is significantly affected by gaps in our knowledge: there is much about disease causation we simply do not yet know. Few data exist, for example, on the health effects of intimate partner violence for males, how climate change affects human health, or the impact of smokeless tobacco.

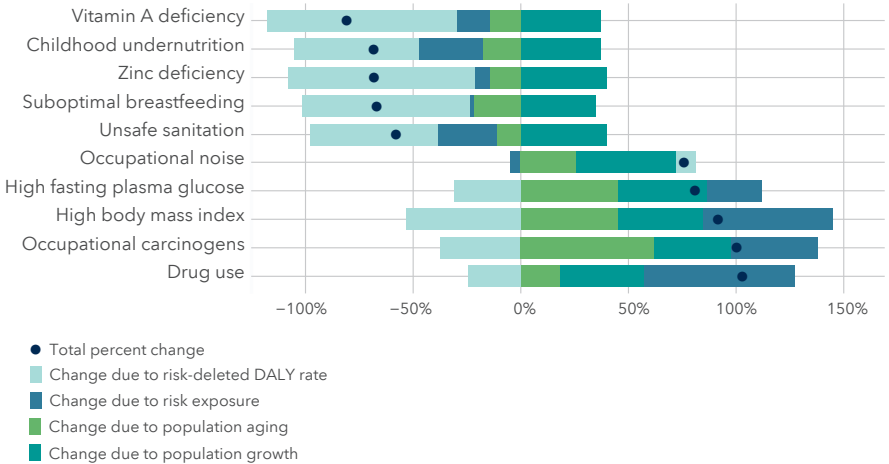
In addition to assessing levels of risk exposure and attributable burden, GBD 2015 estimates the proportion of the increase or decrease in the attributable burden of each risk that is due to population aging, population growth, risk exposure, or changes in the DALY rate that are not due to risk (improvements in treatment, for example). This process of breaking down risk-attributable burden into its components is called “decomposition analysis.” Figure 32 shows the results of decomposition analysis for several risk factors for which attributable DALY rates rose or declined substantially between 1990 and 2015.

Figure 32 shows the total percentage change in the DALY burden attributable to each risk factor (the dark circle in each bar), but also indicates how increases or decreases in population, population age, exposure, or the risk-deleted DALY rate (the proportion of DALYs attributable to risks not measured by GBD) contributed to that change. Risk factors that increased from 1990 to 2015 appear to the right of the center line and those that decreased to the left.

One of the greatest increases in rates of risk-attributable DALYs from 1990 to 2015 was due to occupational carcinogens – that burden went up 100%. That increase in burden was due partly to an increase in exposure (the dark blue part of the bar), but also largely to an increase in population age (light green). The DALY rate due to exposure to risks not measured by GBD declined around 30% (light blue), which is likely due, in part, to improvements in treating different cancers. It is important to note that improvements in treatment can alleviate the disease burden associated with risk factors and even make it appear that exposure to a risk has declined when, instead, health care systems have improved treatment.

Theoretically, the burden of every disease is 100% attributable to risks, but the GBD only analyzes 79 different behavioral, environmental or occupational, and metabolic risks. It does not examine, for instance, how health interventions or genetic factors contribute to disease burden. Risks such as the latter contribute to

Figure 32
DALYs per 100,000, 2015



disease, but not in ways that are fully understood or accounted for in this study. The DALYs attributable to those unknown or unestimated risks make up the risk-deleted DALY rate (some of the risk factors listed in Figure 31, but not included in the GBD analysis, may be responsible for the disease burden captured in the risk-deleted DALY rate). Determining how risk factors affect the burden currently captured by the risk-deleted DALY rate will be a key task for future iterations of the GBD study.

SDI

The Socio-demographic Index (SDI), developed for use in GBD 2015, classifies the levels of development for every country (as well as many subnational administrative units) in the study. That classification is expressed as a number between 0 and 1. The overall SDI value is derived from three separate measures: income per capita, average level of educational attainment, and fertility rate. Each of those measures is laid out on a scale from 0 to 1, with 1 representing the highest income per capita, highest educational attainment, and lowest fertility rate observed. Those rescaled measures are then averaged by country, over the full time period of analysis in this case, resulting in a standardized measure of development across time and geography.

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