Climate Change and Heat-Induced Mortality in India

By: Climate Impact Lab

KEY TAKEAWAYS

1. *India's energy use is expected to more than double by 2040, largely driven by fossil fuels.*

2. *With continued high emissions, the average annual temperature in India is projected to increase from about 24°C to about 28°C by the end of the century.*

3. *The average temperature masks differences across regions. For example, Delhi's current summer average temperature of 31.5°C is projected to increase to over 35°C in 2100.*

4. *Extremely hot days are expected to greatly increase, with days over 35°C increasing from about 5 per year in 2010 to about 42 per year in 2100.*

5. *Punjab is currently the state with the highest average summer temperature. If emissions continue on the current high path, 16 out of 36 states and UTs are projected to be hotter than the current hottest state at the century's close.*

6. *India is projected to see around an increase of death rates due to climate change equal to about 10% of the current death rate. That is, 60 deaths per 100,000 population by the end of the century under a scenario of continued emissions (RCP 8.5).*

7. *By 2100, around 1.5 million more people are projected to die each year as a result of climate change—at a rate as high as the death rate from all infectious diseases in India today.*

8. *India stands to substantially benefit if countries globally take bold actions to reduce emissions. Shifting to a lower emissions scenario (RCP 4.5) sees the excess death rate drop to about 10 per 100,000, a change of about 2% of current levels.*

9. *Taking measures to adapt would greatly improve the heat-related death rate for people living in India.*

The results in this report are drawn from "Carleton, Tamma, Amir Jina, Michael Delgado, Michael Greenstone, Trevor Houser, Solomon Hsiang, Andrew Hultgren, Robert Kopp, Kelly McCusker, Ishan Nath, James Rising, Ashwin Rode, Hee Kwon Seo, Justin Simcock, Arvid Viaene, Jiacan Yuan, and Alice Tianbo Zhang, "Valuing the Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits" (July 31, 2019). University of Chicago, Becker Friedman Institute for Economics Working Paper No. 2018-51.

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Introduction

The world is already seeing signs that the climate is changing, with Summer 2019 breaking records around the world. India experienced its second-longest heat wave, with temperatures reaching 50.8 °C. July 2019 was the hottest month on record globally. Record-breaking warmth is becoming a familiar trend with new markers broken each year for the last several years.

Weather and climate shape India's economy and society. Temperature and precipitation affect such diverse outcomes as human health, labour productivity, agricultural yields, crime, and conflict. When there is extreme weather, it poses risks to daily life, which are only expected to worsen over the century.

At the root of these climate change impacts is the continued global reliance on fossil fuels. India's energy use is projected to more than double over the next 20 years, with much of that new use coming from coal. But as one of the world's largest emitters, India is poised to increasingly take a leadership role in how every country mitigates the causes of climate change. This is why it is critical for the Indian population and policy-makers to understand the benefits of reducing carbon emissions, and the costs to Indian society of not doing so. Without a change to current emissions patterns, India stands to face many impacts of climate change, not least among them being more days of extreme heat.

Extreme heat impacts societies in many ways. One impact that affects both the economy and human well-being is the effect on health, such as through heat stroke and other threats. Heat places the body under great stress, straining the circulatory system and being particularly dangerous to very young children and those over 65. While India is often discussed as one of the countries most vulnerable to future climate change impacts, high temperatures already pose clear and present dangers, as exemplified by the 2015 heat wave that claimed more than 2,500 Indian lives. Reports of people dying from the heat dominate headlines each summer, with even cooler countries like France reporting 1,500 deaths due to the hot temperatures in Summer 2019. India sits at the forefront of this potentially devastating climate impact.

THIS PRESENTS TWO MAJOR QUESTIONS:

- **What are the benefits to India of engaging, and encouraging other countries to engage, in the global mitigation efforts laid out in the 2015 Paris Accord?**
- **What will the impacts be to the Indian population, and how can Indian policy-makers respond, if we continue on a path of high emissions?**

India's Projected Energy Use

(Millions of tons, oil equivalent)

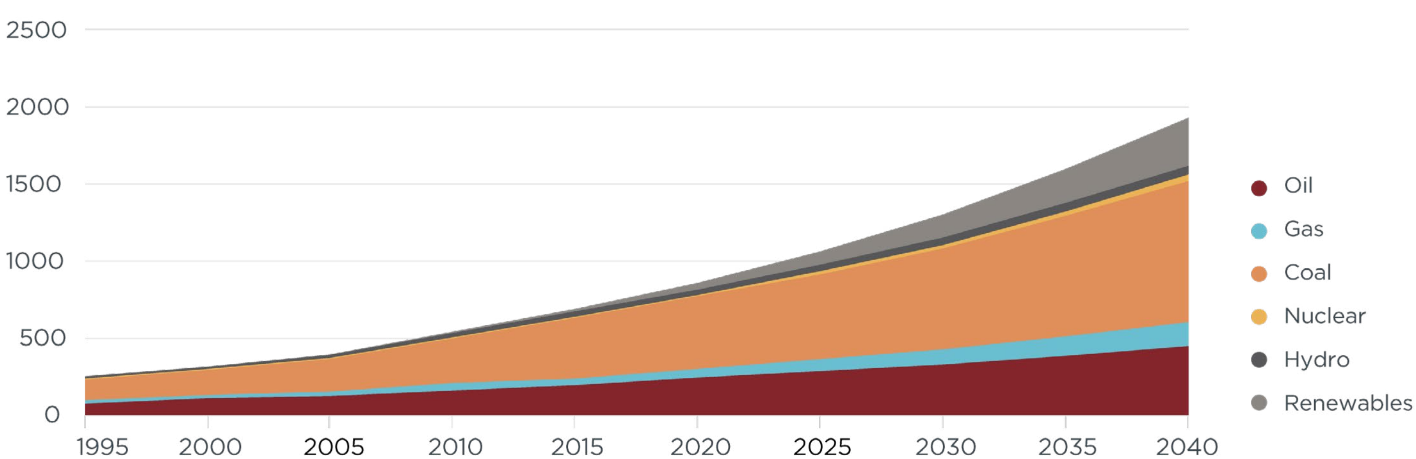

Figure 1: Projected energy use and fuel source in India up to 2040. Source: BP Energy Outlook 2019

As in any other policy domain, decision-makers deserve to be equipped with rigorous, data-driven analyses of damages from climatic extremes. However, at present, policy decisions—whether pertaining to long-term mitigation and adaptation or near-term responses to weather events—are made based upon incomplete, speculative, and highly aggregated estimates of damages. There exist very few comprehensive assessments of how either contemporaneous weather events or future climate change might affect India's economic sectors, even at a nationally aggregated level. Fewer again are based on hard data.

The Climate Impact Lab intends to fill this gap. We have developed India-wide, hyper-local, estimates of temperature changes that can be expected under different scenarios of emissions. Through a massive, data-driven effort to quantify how human health is affected by temperatures, we're also able to see the consequences of these temperature changes on human life. Our approach utilizes outcomes data from around the world to flexibly estimate temperature sensitivities as a function of a location's adaptive capacities, which are proxied by measures of physical and socioeconomic characteristics. This means that we can use data from India today to tell us about India today, but also data from other parts of the world to help us understand what happens as India grows richer and hotter as the century proceeds. We can also see all of this in high-resolution, generating datasets of temperatures and mortality at a localized level throughout India today and in the future.

Average Annual Temperature Change to 2100

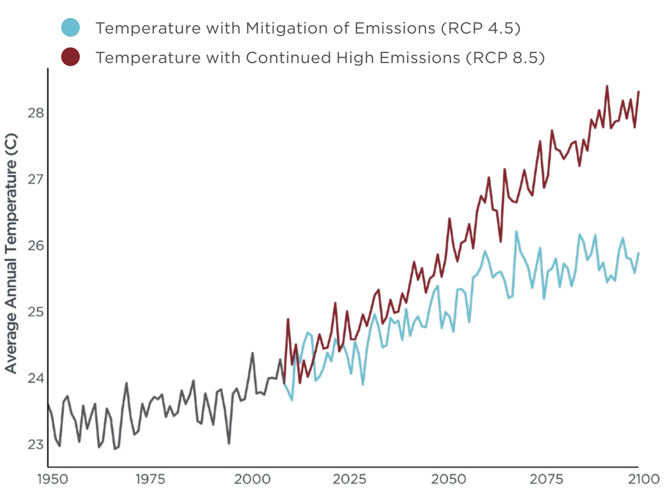

Figure 2: Historical (black) and projected (red and blue) average annual temperature over India up to 2100. The red line shows the temperature projection for a carbon emissions scenario that continues on a current path of high emissions. The blue line shows the temperature projection for a carbon emissions scenario that involves mitigation of emissions slightly above the levels agreed upon in the Paris Accords.

Our Approach

Our approach is rooted in data, to provide the best possible evidence. For our climate projections, we utilize detailed climate data at a highly spatial level from Global Climate Models. These models, 33 in total, are simulations of the Earth's future environment for each year to the end of the current century. All of the models are produced by teams of climate scientists, run on supercomputers, to produce an enormous amount of detailed data. These are the models that have informed global policy-makers about the risks of climate change through institutions like the Intergovernmental Panel on Climate Change.

To link these data to mortality, we have collected the largest dataset ever compiled on human mortality around the world, including India. This lets us quantify how death rates across the globe have been historically affected by temperature, while controlling for many confounding effects. We can also see what role adaptation to different climates has played, and develop a method to estimate the costs of adapting. These data-driven results can be used to project the future impact of climate change on mortality rates and the costs and benefits of adaptation measures populations are likely to undertake to protect themselves from warming. Our mortality data represent 41 countries. Combined, our dataset covers mortality outcomes for 56% of the global population. Data are drawn from multiple, often restricted, national and international sources.

Once we have assembled a large, globally representative collection of historical outcomes data and daily climate data, we can start to understand how climate and health are linked. The comprehensiveness of these data allows us enough flexibility to estimate the relationship of temperature and mortality all over the globe. We can account for varying levels of adaptation across locations by directly examining how the responses vary as people get richer or experience more hot days. Experience matters in dealing with the climate. For example, we can imagine that Delhi is likely better adapted to high temperature days than Srinagar. But we also know that higher incomes help people adapt, through investment in air conditioning and infrastructure improvements that may offer better protection. Our system to project into the future allows us to not only see what the average change might look like, but also how big the risks are of extreme climate change.

The research on health costs of climate change is just the first of several planned analyses that will cover impacts on agriculture, labour productivity, energy demand, and damages to coastal properties. All of these will have the same high level of detail.

Regional Average Summer Temperature Change to 2100

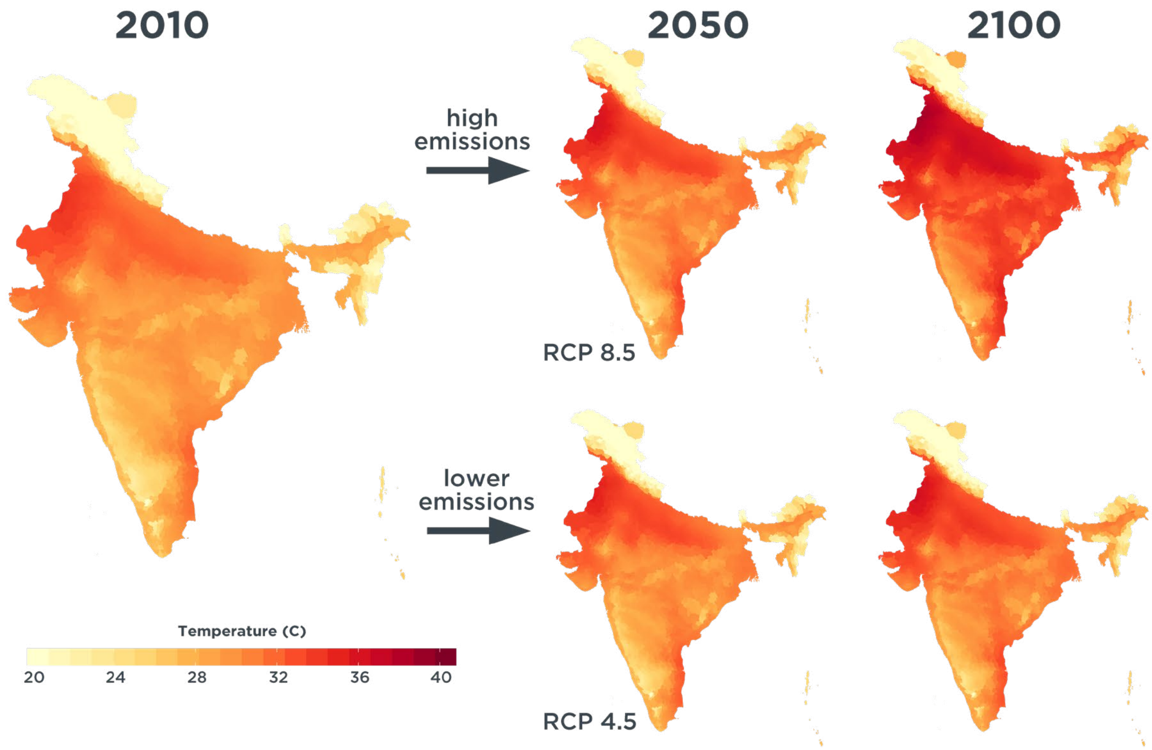

Figure 3: Current average daily summer temperatures for India are shown in the left panel. These averages are calculated over June, July, and August. The smaller maps in the right panel show how the temperatures change spatially under two scenarios: the top row shows the high emissions scenario, RCP 8.5, in 2050 and 2100; the bottom row shows a lower emissions scenario, RCP 4.5, in 2050 and 2100.

India's Climate Future

In order to understand the future of India's climate, it is important to understand its present. Much of the work on climate and health finds that temperatures matter above all else, and so here we only discuss changes to temperatures. As we start to examine other impacts, for example in agriculture, it will be important to discuss aspects of the climate like rain and snowfall, sea level rise, and cyclone strength.

The climate is warming due to the release of greenhouse gases into the atmosphere, largely from fossil fuels used for energy production, transport, and from land use changes. This increase in greenhouse gases, primarily carbon dioxide, prevents the radiation of heat away from the Earth's surface, causing the surface to warm. When discussing the future climate, we must choose a scenario to examine. As figure 2 shows, the temperature changes that India can expect under different scenarios differ greatly. The higher emissions scenario is referred to as "representative concentration pathway 8.5" (RCP 8.5), and it corresponds to a scenario in which the current growth rates of fuel use hold for much of the 21st century. This means that our emissions will grow at a similar rate as in the last few decades. The more aggressive mitigation scenario, RCP 4.5 in figure 2, shows the results of a scenario in which all of the world's countries not only abide by their commitments under the Paris Accord, but also choose to strengthen them as the century progresses.

Figure 3 shows the average summer temperatures for India in the present and into the future under two scenarios. The pattern in the present day shows that north, low-lying regions in the Indo-Gangetic plain regularly exhibit the hottest temperatures in the country, with daily average temperatures of around 30-32°C in the states of Punjab, Haryana, and the capital. Southern parts of the country along the coast of the Bay of Bengal have similarly high temperatures. Much of the variation that is evident in the left panel of figure 3 is due to changes in elevation, with higher elevations being cooler on average.

Two emissions scenarios are shown in figure 3. The top row shows the temperatures under a high emissions, RCP 8.5, scenario. While the overall spatial pattern remains the same, the hotter parts of northwestern India have become more intense, with average daily summer temperatures in the range of 36-38°C in some cases. The bottom row shows the same time periods for a lower emissions trajectory, requiring significant global mitigation efforts. What emerges from this, as well as from figure 2, is that even with substantial mitigation, India will experience some level of warming. In fact, it appears that the end-of-century temperatures under this more aggressive mitigation policy scenario are similar to the middle-of-the-century temperatures for the high emissions scenario.

When we look only at average daily temperatures, we miss two important things that matter to people living in those environments. The first is that we rarely live at the average temperature. Within a season, we are likely to experience hotter days and colder days. It helps to look at how many hot and cold days people in a location will actually experience, rather than just their average.

Figure 4 displays the counts of days in a year, averaged across India, at different temperatures. Each bar is the count of days within a one degree Celsius range (e.g., number of days between 30°C and 31°C). This shows that the summer averages are masking a lot of hotter days. The three coloured plots show the counts of days for three different points of time within the 21st century. We clearly see that the number of extremely hot days is increasing dramatically. For example, looking at the number of days above 35°C, we see a large increase between the blue, green, and finally the red end-of-century, levels. It is these extremes that will have the greatest impacts upon the health of the people who experience them.

The number of extremely hot days across India increases substantially. For days above 35°C, on average, across all of India, there were 5.1 such days per year in 2010. In 2050, under high emissions, there will be 15.8, and by 2100 there will be 42.8. This means that an average district or city in India is likely to experience eight times more extremely hot days per year.

The other often missing piece of the climate change discussion is that people often only talk about mean projected changes. That is, the averages of the many global climate models. In fact, there is a probability of more extreme or less extreme climate changes captured by these models. This is a critical piece of information for policy makers, as the uncertainties of future climate changes can inform how much investment we make in climate or adaptation policy.

Changes in Number of Extreme Temperature Days

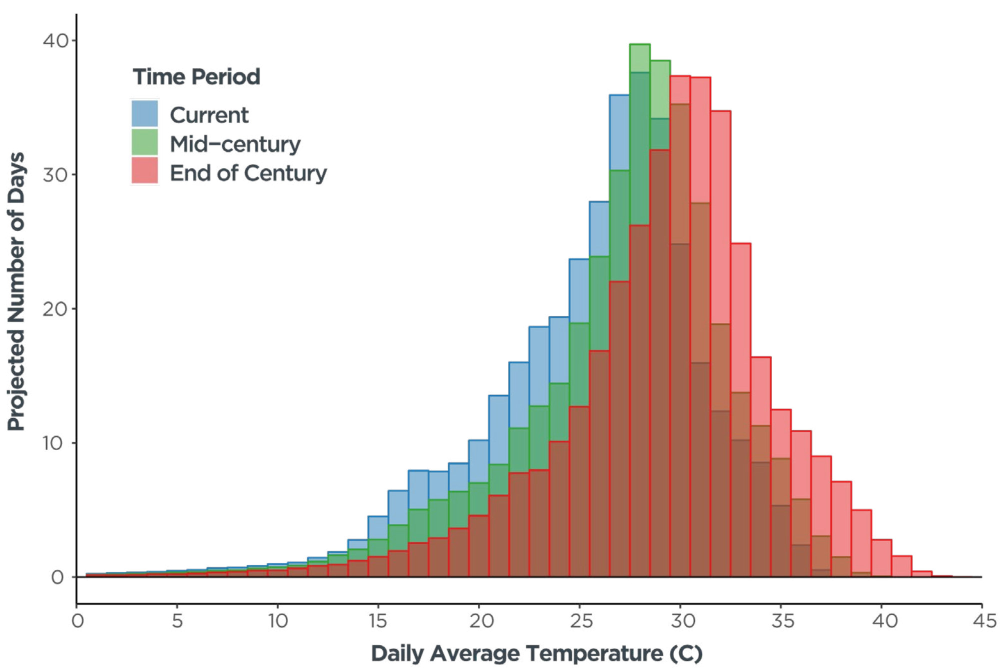

Figure 4: Counts of number of days at within a range of a single degree Celsius, averaged over India, for three time periods. This is calculated by counting the number of days at specific temperatures for each subdistrict and city in India and then taking that average over the number of locations. The three colours represent time periods during the century, from current (blue), to mid-century (green), to end of century (red).

Comparison of State Summer Temperature Changes

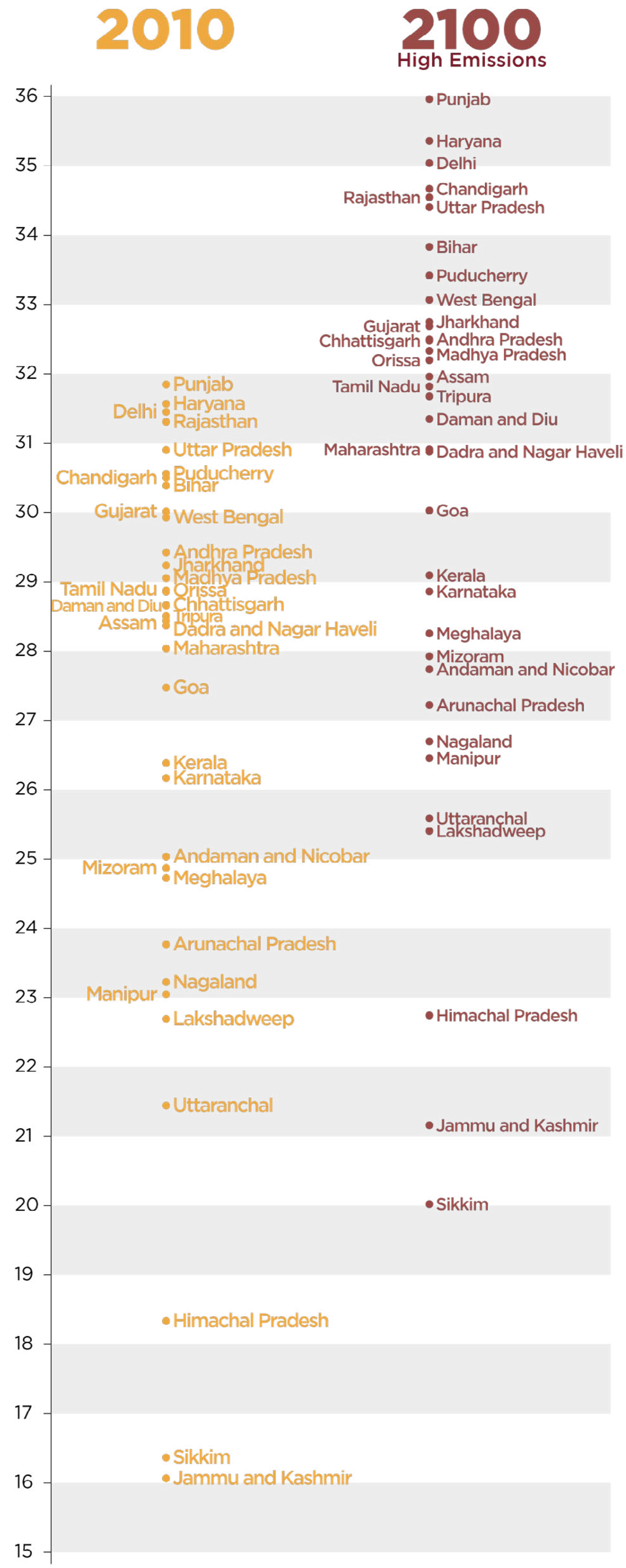

Figure 5: Average summer temperatures for each state and UT in India in 2010 and in 2100 under high emissions.

Finally, it is often difficult to imagine what a climate change of 2, or 3, or 4°C will feel like. The final figure in this section, figure 5, allows us to compare our future climate of tomorrow by seeing how it compares to another location's climate today. Punjab, Haryana, and Rajasthan are the three hottest states in terms of their summer temperatures in India today, with Delhi being equally as hot. Punjab's average daily summer temperature in 2010 was just below 32°C. The current summer daily averages are shown in the left side of figure 5.

The right side of figure 5 shows the average daily summer temperatures for each of the states in India under the scenario of continued high emissions. What we see is that 16 out of the 36 states and Union Territories are projected to be hotter than Punjab is today. Even the coldest states have warmed substantially, sometimes by more than 5°C. States like Gujarat and Andhra Pradesh will warm to temperatures easily in excess of today's highs in Punjab. This begins to give a sense of what temperature changes may mean for a local population, as we start to examine the effects of such environmental change.

Heat, Health, and Adaptation

What exactly is the relationship between temperature—both hot and cold—and mortality? How do we attribute deaths from a diverse set of causes to heat? How, and how much, do people adapt to extreme hot and cold temperatures and what does it cost them to do so? What implications do these relationships have as the world heats up over the coming century? Knowing the answers to these questions at a local, national, and global scale would be of tremendous practical value to policymakers, city planners, business leaders, and a range of stakeholders looking to mitigate these effects and prepare for future risks.

Historically, researchers have struggled to provide credible understanding of the damages inflicted by climate change at a local scale. Even just from a data perspective, the data simply have not been available, and the result has been analyses that are insufficiently complete in scale and scope to credibly describe a global response to warming. Further, there has not been a clear method to quantify the costs and benefits of adaptation. Because of these difficulties, theoretical models have been widely used to capture the global nature of the problem and provide an answer to the question of what the global costs of climate change will be. However, the many untested assumptions implicit in these models weaken the authority of these answers. Thus, to date, there have been few, if any, comprehensive, spatially-resolved, data-driven studies of climate impacts that account for adaptation.

By combining comprehensive historical mortality records to detailed local variations in exposure to heat and cold, we quantify how death rates across the globe have been affected by observed changes in the climate. Our data represent the largest sub-national vital statistics database in the world, detailing 399 million deaths across 41 countries accounting for 56% of the global population. Combining these records with temperature observations, we find that both extreme cold and extreme heat have important effects on death rates that are modified by the climate and income levels of the affected population. We measure income by the average wealth in a state. Richer states can adapt better due to more ability to spend on adaptive measures and better infrastructure. But experience also matters. We measure this by looking at people's average temperature, which captures how many extremely hot days they will usually experience.

Before looking at India, it is helpful to discuss what this adaptation actually means. The risks of extreme temperatures vary around the world depending on how wealthy a country is or how warm the climate is. Having resources to invest in adaptation enables countries to reduce mortality risk from warming, as does previous experience of living in hotter temperatures. For example, in the wealthy and warm city of Houston, Texas, the impact of a single hot day on the annual mortality rate is just 0.4 deaths per 100,000. In the wealthy but colder city of Seattle, Washington, and in the warm but poorer city of Delhi, India, the rate is roughly double—0.8 deaths per 100,000. However, with many more of these hot days every year in Delhi, the total number of lives lost to heat in Delhi far exceeds those in Seattle. This is how adaptation can help decrease the impacts of climate change.

Mortality-temperature relationship estimates are used to generate projections of the future impacts of climate change on mortality rates for areas across the globe. We use data on India to capture what is occurring today, and data from warmer places (like Southern Mexico) or wealthier places (like the Northern United States) to inform us in how much adaptation we might see in the future. We also include the costs of adapting to climate change, to give us the full mortality risk associated with climate change. Now we zoom into the results for India.

Heat-related Death Rates in India to 2100

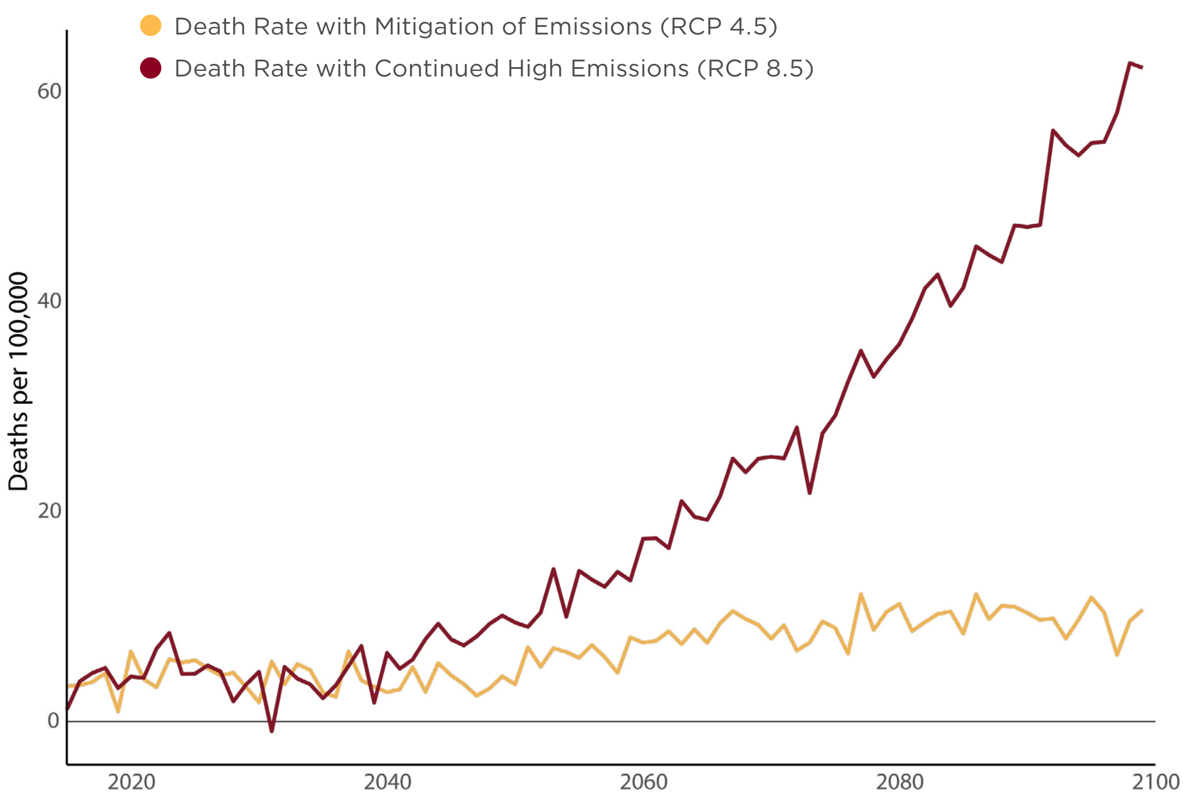

Figure 6: Changes to death rates under two scenarios. Lines represent the all-India average change in death rates due to temperature.

High emissions cause a large increase in excess deaths due to temperature in India. Figure 6 shows the total change in the death rate across India for each year from now until the end of the 21st century. The red line shows that by 2100, continued high emissions would lead to a projected 60 extra deaths per 100,000 population, even accounting for adaptation. The baseline death rate in the early 2000s in India in our data is 550 per 100,000 population (though there is likely to be some underreporting). That means that the excess climate change deaths would be an extra 10% increase upon current death rates. To put that in terms of total numbers, this excess death rate amounts to a total of 1.54 million excess deaths per year due to climate change by 2100 under high emissions.

The benefits of mitigation become clear by looking at the yellow line. This is what India would experience if the world not only committed to the Paris Accord agreement, but also engaged in the planned updates to each country's commitments. Under that scenario, the excess deaths drop to about 10 per 100,000—a drop of over 80%.

Every part of India does not suffer equally. Figure 7 shows a map of the full mortality risks for India, under high emissions, in 2100. Locations in the hotter northwest or southeast show large increases in death rates, but many parts of the country with milder temperatures also show large increases. Some areas, those in blue, show actual declines in death rates, since they benefit from the reduction in the numbers of harmful cold days. Unlike many countries at higher latitudes, which may see only health benefits as they warm, India tends to see negative impacts on average for a much greater share of the population. It is, in many ways, a country at the forefront of the impact of climate change.

Full Mortality Risk of Climate Change in 2100 (deaths per 100,000)

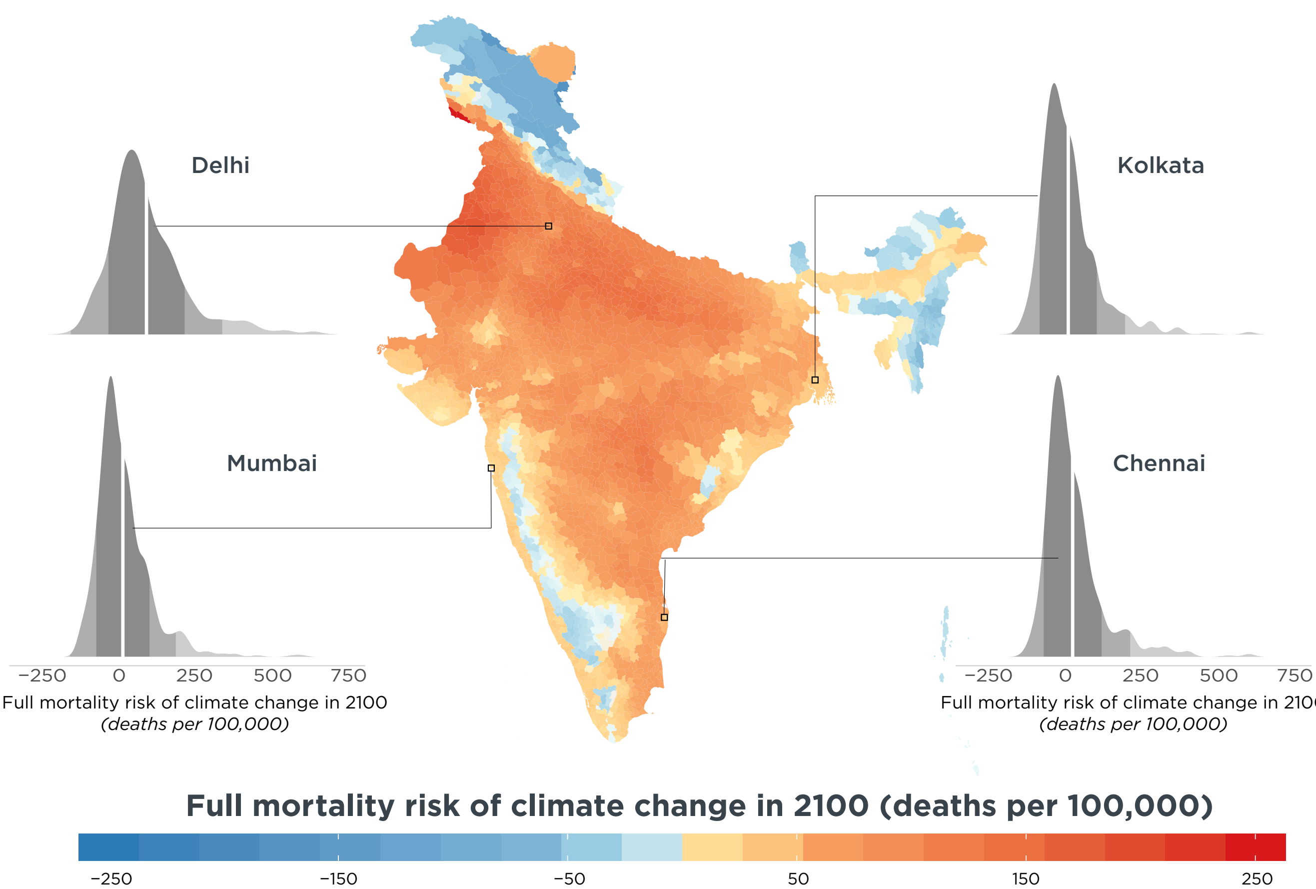

Figure 7: Full mortality risk of climate change in 2100 under a high emissions (RCP 8.5) scenario. Red areas are those with a projected increase in mortality, while blue areas are those with a projected decrease. Averages for each location are shown on the map. Histograms for selected cities show the full distribution of risk for those locations.

Impacts of Climate Change in 2100 Compared to Current Disease Death Rates

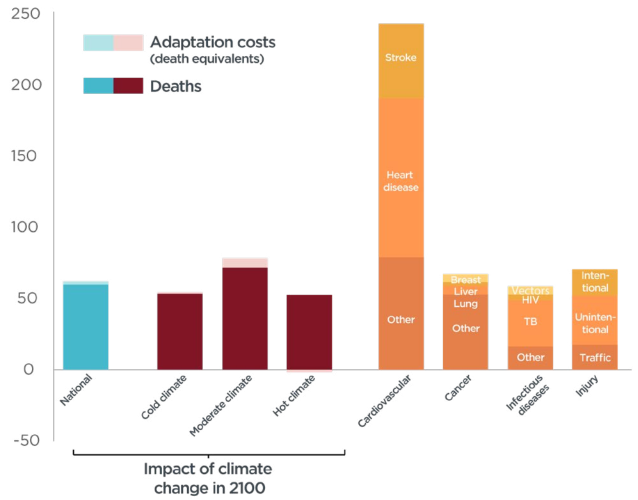

Figure 8: Deaths plus adaptation costs due to climate change in India in 2100 (green and red bars) compared to deaths in 2017 due to some other leading causes. Source of current disease burden: IHME, Global Burden of Disease 2018.

Benefits of Mitigation for India and Global Comparison

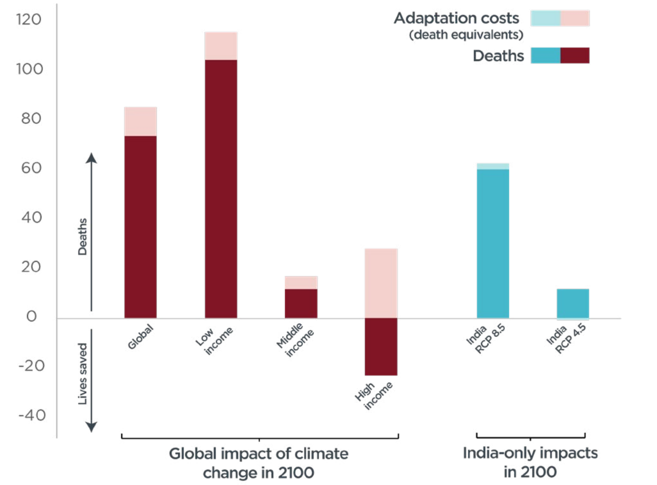

Figure 9: Red bars show death rates plus adaptation costs for the entire world (global average), and for World Bank income group classifications. Green bars show India death rates plus adaptation costs for higher and lower emissions scenarios.

It is important to note that there is often a wide range of projections for locations. Figure 7 also shows the potential distribution of impacts for a number of large cities. What is worth noting is that these distributions are not symmetrical. This means that if the environment is more sensitive to carbon dioxide than science currently thinks, on average, the resulting effects are likely to be much worse than we expect.

To put these numbers into context, compare the total projections in 2100 against some categories of the current disease burden in India. Figure 8 shows that all the deaths from climate change in India under a high emissions scenario are of comparable size to the reported deaths due to all cancers, or all infectious diseases, in India today. They are approximately three times larger than the reported traffic accidents in India today, and one third of the death rate from heart disease, stroke, and other cardiovascular causes. Digging deeper into the national average and looking separately at the colder, moderate, and hotter thirds of the country, we see a pattern of adaptation. The coldest parts of the country, many of them at high altitudes, begin to benefit from a reduction in cold days, resulting in an impact that is lower than the national average. For the hottest regions, the effect of experience in dealing with hot days reduces them below the national average as well.

Mitigation has clear benefits for India. Being on a lower emissions trajectory would decrease the deaths from about 60 per 100,000 to about 10 per 100,000—meaning mitigation decreases the excess temperature-induced death rate by about 80%. India is actually lower than the global average that we project, which is approximately 85 deaths per 100,000. But, by the end of the century, it is lagging far behind the current high income countries, which have a total impact of about 5 deaths per 100,000 after having spent significant resources on adaptation. One implication of this is that with resources beyond what would historically have been deployed on adaptation, India has a significant margin by which it can reduce the mortality impacts of climate change. However, this will be costly, and especially so in the high emissions scenario.

Conclusion: Choosing a Path

India's government and private decision-makers have been informationally impaired in anticipating the economic and social repercussions of extreme weather, both now and in the future. In addition to shedding light on local temperatures and the sensitivity of health to temperatures, the methods developed in this project also have the potential to be used as a near-term forecasting tool, a guide for adaptation policy planning, and a resource for counting the costs to Indian society as climate change progresses. Such a tool can equip policymakers with valuable information for better allocating scarce resources to areas of immediate concern.

While it is widely acknowledged that India is vulnerable to near-term weather events, as well as long-term climate change, there have previously existed no comprehensive analyses on how these vulnerabilities matter in specific locations. As a result, the Climate Impact Lab hopes to remedy this deficiency and yield unprecedented, hyper-local insights into climate risks for India. These results provide important information for policymakers forming policies to reduce the impacts of climate change because they capture the benefits of reducing CO_2 emissions to mortality. Further, the results provide estimates of the changes in mortality risk for individual sub-districts and cities. Having this localized information provides key insights for local and national policymakers debating the importance and value of investing in adaptation measures.

The projections in this report represent the first empirically-derived estimate of the impacts of climate change for a single sector of the Indian economy. This is the first in a series of analyses that will apply similar levels of detail to data-driven projections of other sectors of the economy (e.g. agriculture, energy systems), which will enable the calculation of the full benefits to India of choosing, and advocating for, a path of reduced reliance on fossil fuels.

ABOUT CIL

Climate Impact Lab

The Climate Impact Lab inks state-of-the-art climate model-ing, economic statistics, and big data analytics to build the world's most comprehensive body of research quantifying the impacts of climate change around the globe.

impactlab.uchicago.edu

ABOUT TCD

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