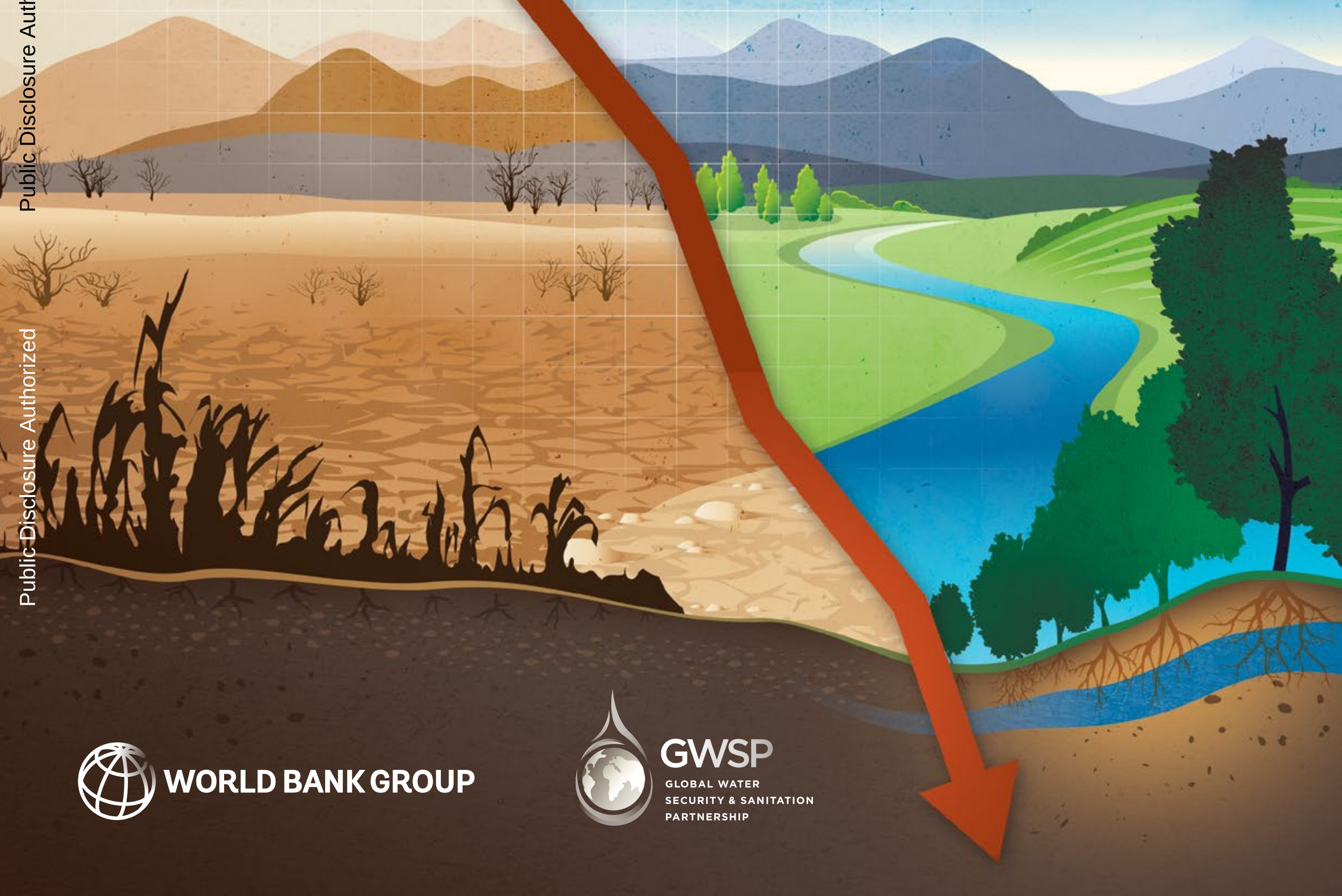
WATER GLOBAL PRACTICE WORKING PAPER

DROUGHTS *AND* DEFICITS

Summary Evidence of the Global Impact on Economic Growth

Esha Zaveri
Richard Damania
Nathan Engle



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Working Paper

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Executive Summary

This paper presents new estimates of the effects of dry episodes (rainfall shocks) and droughts on gross domestic product (GDP) per capita growth rates using state-of-the-art empirical methods. Rainfall and water availability exhibit considerable spatial variability that is almost two times greater than that of temperature. Hence, the analysis needs to be conducted at a high degree of spatial disaggregation to capture the effects of rainfall variations on economic indicators of interest.

A first key finding of the assessment is that dry episodes have been growing in frequency and geographic coverage over the past half century, which is consistent with the projections of some climate change models. However, much of this drying has occurred in low- and middle-income countries, with no such trend observable in temperate zones, where most developed countries are located.

Estimates of the effects of dry episodes on GDP per capita growth rates are provided at the grid cell level (around 56 kilometers by 56 kilometers at the equator). The results from a large number of empirical estimates consistently show that dry shocks are especially harmful to economic growth in developing countries. Compared to normal conditions, moderate drought reduces growth in the developing country sample, on average, by about 0.39 percentage points, and extreme drought reduces growth, on average, by about 0.85 percentage points. The average growth rate over the time period of the sample was 2.19 percent, implying that even moderate shocks can send impacted areas into a growth slump. In high-income countries, moderate droughts have no impact, and only extreme droughts have adverse effects, reducing growth by about 0.3 percentage points, which is a little less than half the impact felt in the developing sample for the same intensity of drought.

However, the impact of a dry shock of a given magnitude can vary considerably across different locations in developing countries, and can vary over time at a given location:

- **Adverse impacts on growth are greater in arid and semi-arid areas**, reflecting harsher baseline conditions.
- **At any given location, cumulative rainfall in the recent past also determines the growth impacts of a dry shock.** Rainfall increases in previous years raise soil moisture in the root zone of crops and can neutralize the harmful impacts from a dry shock. Conversely, if recent years were drier than normal, the headwinds on economic growth from dry rainfall shocks are considerably stronger. Local and upstream forest losses are key channels through which these impacts manifest, highlighting the importance of supporting green water functioning and climate resilience. These are perhaps the first empirical findings that quantify the importance of "green water" (soil moisture) in shielding economic growth from adverse rainfall shocks.

The paper concludes with an atlas of growth losses caused by dry shocks over the sample period at a fine level of spatial disaggregation. These estimates provide a starting point for identifying the risks and vulnerability to drought in and between countries. They also signal the magnitude of losses from the often hidden economic costs that dry shocks and droughts bring, and can help policy makers to target interventions to areas of greatest impact.

The findings have several implications for development practitioners. They highlight the need for stewardship of forests and other natural capital that affect the hydrological cycle but are seldom associated with the growth impacts of droughts. They also highlight the need for proactive investment to address vulnerabilities through upgrades in information systems, institutions, and infrastructure that build drought resilience. Global experience supports the following interventions:

- Development, implementation, and integration of early warning systems where they are lacking or insufficient.
- Infrastructure investments, including storage, nature-based solutions, groundwater and managed aquifer recharge, desalination, water reuse and recycling, nonrevenue water reduction, irrigation schemes, and rainwater harvesting.
- Institutional strengthening such as through drought policy, legislation to codify roles and responsibilities, and standing drought committees.
- Risk financing mechanisms tailored to vulnerable groups in each country.
- Coordinated planning at multiple levels for short-term emergency planning and long-term planning across utility, city or town, river basin, province, and national levels.

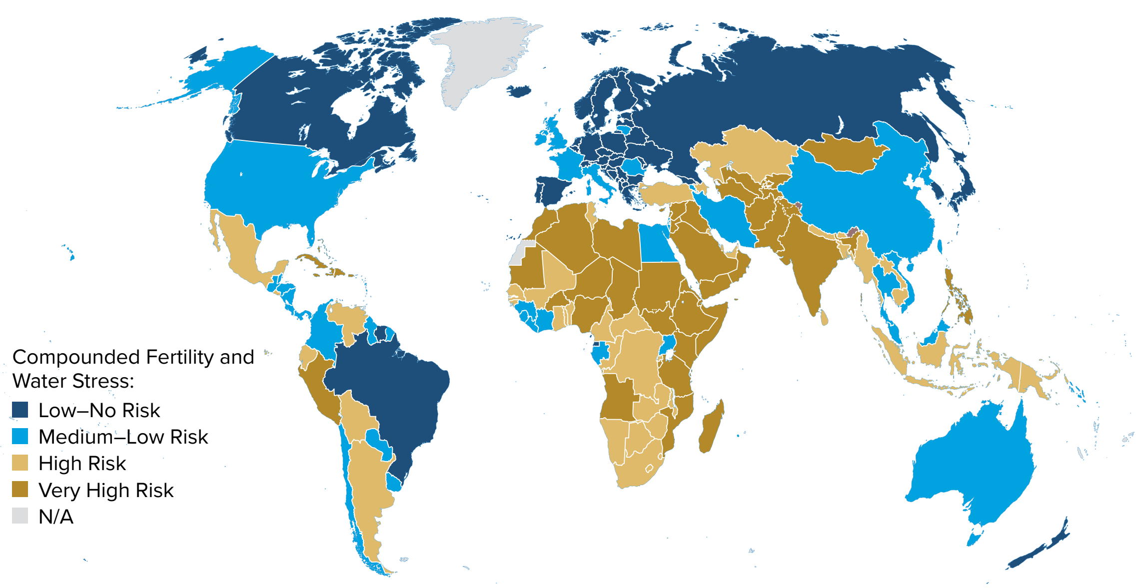
There is considerably more work to do on this agenda, and the World Bank can help structure a more cogent program around drought resilience building through its upcoming engagement, which can be offered to clients across the World Bank regions.

Introduction

Water deficits will soon become the new normal through much of the world. With rising human populations and growing prosperity, water demand is growing exponentially, while damaging human activities are degrading and diminishing water supplies (watersheds, rivers, lakes). The result is a water deficit, with stresses that will spread to new regions of the world and worsen in areas where water is already scarce. Around 60 percent of humanity live in a water basin that encounters water stress for at least part of the year (Mekonnen and Hoekstra 2016). Map 1 overlays projected population growth with the availability of water in 2050. It starkly illustrates that even without further degradation of water resources, it is the poorest and the driest regions of the world that would face the most severe scarcity and water related challenges. It is notable too that many of these countries are classified as "fragile," and some are in conflict.

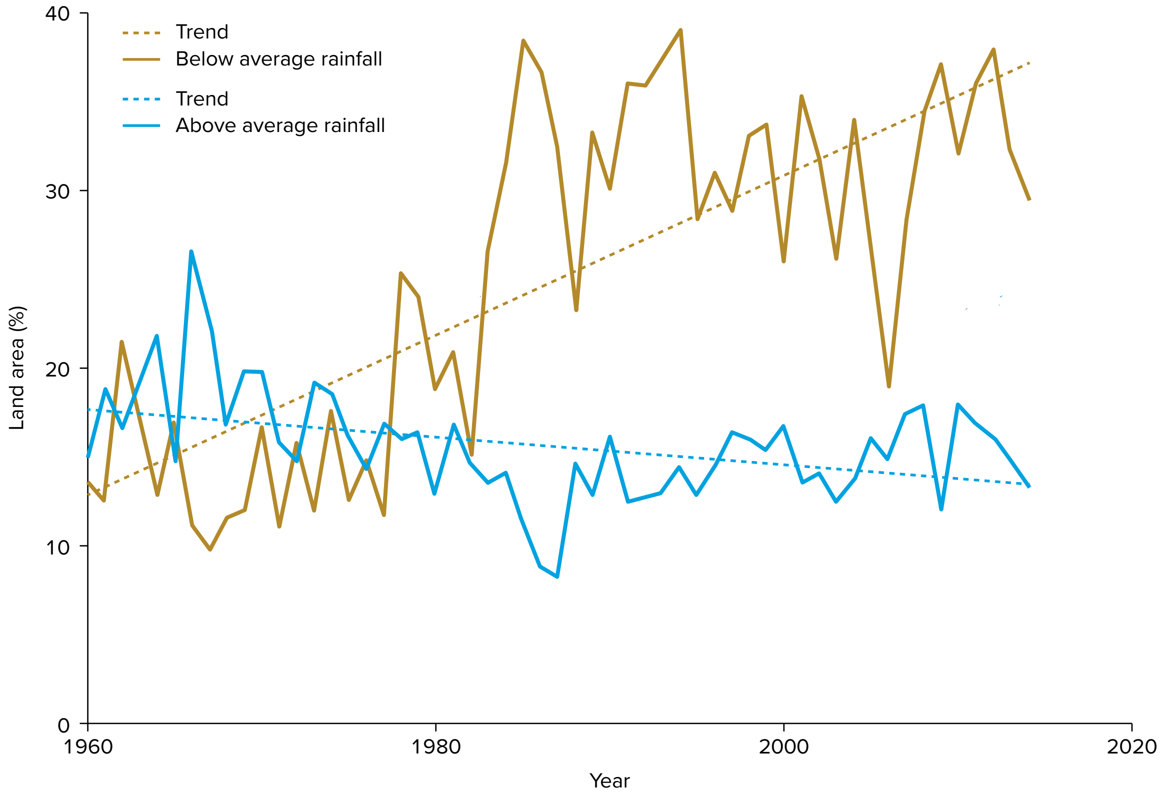
Climate change compounds these challenges by making rainfall more variable. Though future rainfall projections are highly uncertain, there is unanimity across climate change models that rainfall will become more erratic and extreme with rising temperatures. There are already clear signs that rainfall variability has increased significantly over the past five decades. Figure 1 shows a distinct drying trend over the past half-century. The proportion of land encountering dry shocks has increased, and areas with above average rainfall are

Map 1 Global per Capita Water Availability and Future Population Growth, 2050



Source: World Bank.

Figure 1 Global Trends in Land Area with Above- and Below-Average Rainfall, 1960–2020

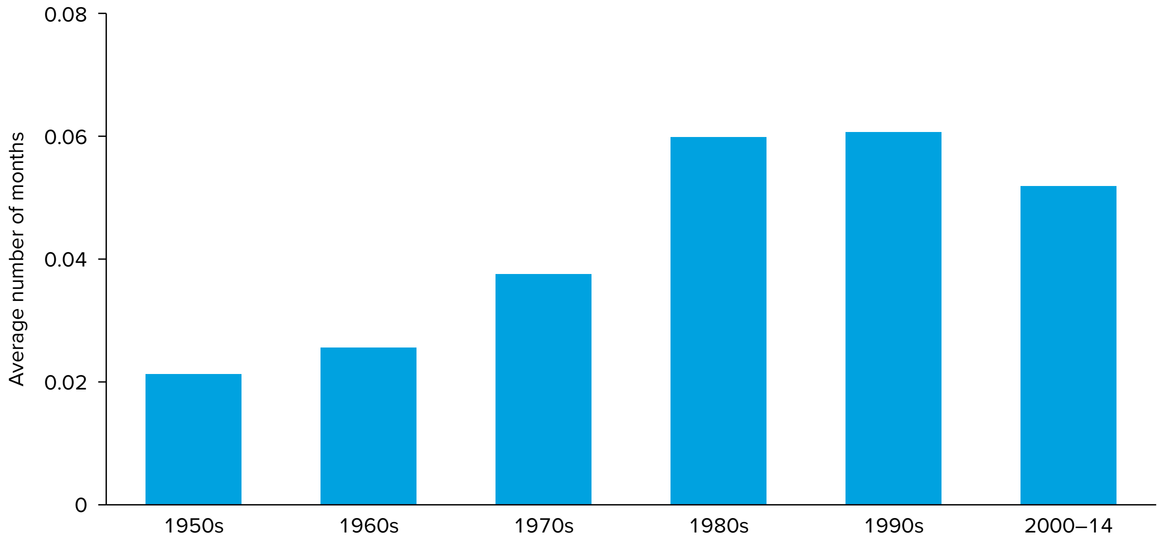


Source: World Bank.

in decline. These empirical findings are consistent with scientific projections that the global land area and population facing extreme droughts could more than double from 3 percent during 1976–2005 to 7–8 percent by the late 21st century (Pokhrel et al. 2021).

Dry rainfall shocks are a key, underappreciated development challenge for low- and middle-income countries. Figure 2 shows that low- and lower-middle-income countries are particularly affected by this drying trend, but there is no such pattern among higher-income countries, which are typically in temperate and moist biomes. In the last five decades, the frequency of extreme dry shocks[1] have substantively increased. The average number of such episodes has increased by about 233 percent. Over 85 percent of people affected by dry shocks live in low- or middle-income countries (Damania et al. 2017). Climate models project that variability will intensify in some of the world's driest regions, including the Middle East, North Africa, and Central Asia (Hall et al. 2014). Adapting to rainfall variability is often much more challenging than accommodating long-term trends because of the unpredictable duration of a deviation, its uncertain magnitude, and its unknown frequency.

Figure 2 Rainfall Trends in Low- and Lower-Middle-Income Countries, 1950s–2014



Source: World Bank.

Note: Data indicate extreme dry events.

The drying trend is accompanied by the growing frequency of extreme rainfall events. In 2018 and 2019, Europe witnessed two exceptional droughts, which scientists called unprecedented in the last 250 years. In July 2021, record-breaking rainfall brought severe floods to Europe, where 200,000 properties lost electrical power. In the same month, torrential rain with a maximum intensity of 201.9 millimeters in a single hour led to devastating floods in Henan Province, China, forcing more than 1 million people to relocate. These flooding events each caused roughly US$12 billion in property damage (Liang 2022). And just this past year, drought conditions in eastern Ethiopia, northern Kenya, and Somalia led the UN to warn that some 22 million people could be at risk of starvation. In Somalia, the rainfall in the March to May season was the lowest in the last six decades. And large parts of the Democratic Republic of Congo and Uganda have experienced very dry conditions compared with the average.

Even as water scarcity is a growing problem, floods have captured the attention of policy makers. Floods are visible, high-impact events that destroy infrastructure, damage homes, and disrupt livelihoods. They are difficult to ignore. Droughts, in contrast, are spatially diffuse, harder to identify, and more complicated to comprehend. Their impacts can emerge gradually and less visibly and have been referred to as *misery in slow motion* (Damania et al. 2017). There is a growing body of evidence that water scarcity and droughts can have significant, long-term impacts on farms, firms, and families. They can compromise agricultural systems, accelerate the destruction of forests, hamper firm productivity, and significantly affect the health of women and children. Dry shocks cascade consequences from declining agricultural yields to shrinking forest cover. Faced with declining agricultural productivity due to droughts, farmers often seek to recoup these losses by expanding cropland at the expense of natural habitats (Zaveri, Russ, and Damania 2020). For urban firms, the economic cost of droughts is four times greater than that of floods, with even more severe and longer-lasting effects. Droughts cause water shortages, power outages, and stalled economic momentum (Desbureaux and Rodella 2019; Islam and Hyland 2019). For far too many families, drought is also destiny. A dry shock in the first 1,000 days of a child's life shapes their future. In rural Africa, female infants born during severe droughts will bear the marks throughout their lives, growing up physically shorter, receiving less education, and ultimately, becoming less wealthy (Hyland and Russ 2019). Perhaps most troubling, the legacy of droughts can ripple through generations, harming not just the women who experienced them but also their children, who are more likely to suffer from malnutrition. The silent crises of droughts can have much greater economic impact than is recognized.

This report demonstrates that rainfall deficits have material impacts on GDP per capita growth rates. There is considerable heterogeneity across countries and over time. Recent and past climate history are key factors in determining the magnitude of impacts (all else equal). When recent years are drier than normal, the headwinds on economic growth from dry rainfall shocks are found to be considerably stronger. Conversely, if the recent past has been exceptionally wet, a one-off dry rainfall shock has a more muted impact on economic growth. Local and upstream forests losses are key channels through which these impacts manifest, highlighting the importance of halting forest loss to support green water functioning and climate resilience. These findings, perhaps the first empirical estimates, highlight the importance of "green water" (soil moisture) in shielding economic growth from adverse rainfall shocks. Negative growth effects are also found to be heavily concentrated in developing countries in arid and semi-arid regions. The disproportionate impact on poorer countries is a consequence of the often harsher climatic conditions and the limited resources to manage the consequences of dry shocks and droughts.

NOTE

1. Defined here as shocks that are at least 2 standard deviations (SDs) below the long-term mean. Note that a 2 SD dry shock is a very rare event and includes the driest 2.5 years in a century.

Objective

Recognizing that rainfall shocks are growing in frequency, this paper quantifies their economic consequences at a high level of spatial disaggregation. A better understanding of the economic effects of greater rainfall variability and identifying vulnerable locations will allow developing countries to help steer policies and target adaptation investments to vulnerable areas that are most affected. This paper uses state-of-the-art empirical methods to present new estimates of the economic growth impacts of dry and wet rainfall shocks. Such spatially refined information is especially useful for adaptation planning. The near-term focus is also apt since it limits the very large uncertainties regarding future rainfall associated with the projections of climate change models.

Approach and Methods

Several techniques are available to estimate impacts of rainfall shocks. These include bottom-up models, simulation methods that employ combined climate and economic modeling, and more recent reduced form regression approaches.

Bottom-up models specify how particular sectors use water and how rainfall variations may affect productivity levels in these sectors. An advantage is that they provide an understanding of how changes in water availability affect key sector outcomes. However, it is impossible to model all possible impacts of water because it is used implicitly or explicitly in all production and supports all life. Errors of exclusion would likely lead to downward biases in estimated impacts. A further disadvantage is that the approach ignores interactions between sectors that may magnify or diminish the overall effect of shortages or excess rainfall on GDP. As an example, if a rainfall shock leads to an employment decline in the agricultural sector, lower wages in labor markets may boost employment and output in other sectors. This would partly compensate for the decline in agricultural output. But the reverse could also occur. A decline in agricultural incomes could lower aggregate demand in the economy and lead to a decline in output. In sum, the direction and magnitude of bias from bottom-up modeling approaches are, a priori, unknowable.

Another popular way of estimating impacts is through simulation models. Examples of this approach include computable general equilibrium (CGE) models and integrated assessment models link climate models to an economic model. A variant of these are hydro-economic models that connect hydrological models to an economic module. These models often have detailed specifications of each sector of the economy and may also allow for interactions between sectors and thus offer a more complete assessment of possible impacts. A strength and contribution of the simulation approach is that it can estimate the impacts of hypothetical scenarios and futures, thus enabling policy makers to determine the likely magnitude of impacts. A drawback is that results are driven by model assumptions, which may not reflect economic reality. For instance, most CGE models assume that inputs such as physical capital or human capital are close substitutes for water. This means that a tractor (physical capital) can substitute for a depleted aquifer, so that running out of water would have little or no economic impact. Crucially, results in simulation models depend upon these key assumptions, and it is often unclear which of the many assumptions and parameters drive model results.

This paper takes a different approach and uses recent econometric methodologies to causally identify and quantify growth impacts of precipitation shocks. Rather than identifying pathways through which water affects growth and summing up, this approach examines the effects on a single and perhaps crucial aggregate measure: economic growth. An advantage is that it estimates aggregate outcomes directly rather than relying on a priori assumptions about what mechanisms to include and how they might operate, interact, and aggregate. A disadvantage is that it cannot identify the pathways through which water affects economic growth. Another shortcoming is that the approach calls for careful specification of the estimating equation to consider the myriad effects on GDP.

Following best practices, the analysis models the effect of shocks on growth in GDP per capita, instead of levels of GDP per capita, because GDP exhibits trends (that is, high levels of serial correlation that are indistinguishable from a random walk and have a unit root). The reasons for this approach are largely statistical. Because unit root processes have trends (are nonstationary), regressions that use nonstationary variable often generate spurious results. To avoid the statistical pitfalls associated with regressions of trending variables, the exercise is performed in terms of changes (first differences). This also has important dynamic implications for the persistence of impacts. If rainfall shocks were to affect the level of GDP, it suggests a temporary impact that disappears the following year. For example, this may occur if yields collapse one year and recover the next year. But if there were an impact on the *growth* of GDP, this implies persistence because growth effects compound over time. Regressions in appendix A show that growth impacts persist for three years after a dry shock, after which there is a reversion to the previous growth rate. Box 1 provides a more formal explanation of the estimating approach. Further details are provided in a technical working paper (Zaveri, Damania, and Engle 2023).

Box 1 Empirical Methodology

It is challenging to estimate water's causal impacts on aggregate economic outcomes such as per capita GDP or GDP growth. Water shocks could affect GDP growth through many channels. Some might be location-specific (such as the topography of a grid cell), others might vary over time in each grid cell (such as population), and yet others may affect all grid cells uniformly over time (such as a global banking crisis). Variables termed fixed effects account for these unknown and unmeasured factors to isolate the impacts of precipitation changes on the variable of interest.

The econometric specification uses a panel fixed effects model to link data on droughts to data on economic growth at the level of 0.5-degree grid cells (approximately 56 kilometers × 56 kilometers at the equator) between 1991 and 2014, the time period for which economic data are available at a granular scale. This is done by overlaying a global database of historical weather from Matsuura and Willmott (2018) and annual grid-level GDP data between 1990 and 2014 from Kummu, Taka, and Guillaume (2018). The data are based on subnational GDP per capita data constructed by Gennaioli et al. (2013) and covers 82 countries, representing 85 percent of the global population and 92 percent of global total GDP (purchasing power parity) in 2015.

To estimate the impact of droughts on economic growth, the analysis follows much of the empirical climate change literature and estimates a reduced-form production function-style equation. For each 0.5-degree grid cell and year, the annual growth rate of the cell's GDP per capita is calculated adjusted for inflation (g), and the following equation is estimated to determine if g is impacted by different levels of drought severity (B1.1):

$$g_{i,t} = f(D_{it}) + \beta X_{it} + \gamma_i + \varphi_t + \mu_{c \times t} + \varepsilon_{i,t}. \quad \text{(B1.1)}$$

Cells are indexed by i and years by t. Thus, the unit of observation is the grid cell year. The relationship between growth and droughts, $f(D_{it})$, could take many forms. To measure droughts, rainfall variability is measured in terms of local deviations from the long-run mean. This is plausibly exogenous because it reflects random draws from a climate distribution (Dell, Jones, and Olken 2014). Much like the Standardized Precipitation Index (SPI), rainfall variability is measured using z-scores. To define when a grid cell experienced a shock, the z-score of rainfall is calculated in each grid cell, and each time period as per $z_{it} = \frac{rain_{it} - \overline{rain_i}}{\sigma_i}$, where z_{it} is the z-score of rainfall in grid cell i at time t, $rain_{it}$ is rainfall in grid cell i at time t, $\overline{rain_i}$ is mean rainfall in grid cell i over the full time period of the climate dataset, and σ_i is the standard deviation of rainfall in grid cell i over the same time period. The z-score for rainfall is interpreted as the number of SDs away from the long-run mean in time t. Once z-scores are calculated, binary variables are generated to indicate whether the z-score passes certain thresholds.

A grid cell is considered to have a *dry shock* if rainfall in a given year is lower than the long-run annual mean for the grid cell by at least X SD ($z \leq X$) where X can be any range of integer values. Similarly, a grid cell is considered to have a *wet shock* if rainfall in a given year is higher than the long-run annual mean for the grid cell by at least X SD ($z \geq X$). Doing this allows for a semiparametric test of the impacts of deviations from the long-run mean. It also allows for impacts to be both nonlinear and nonsymmetric around zero. These properties are important for distinguishing the possible heterogeneous impacts of deluges versus droughts. In figures 3–5 and figure 10, a threshold of $X = 1$ is used. In other specifications, as in figures 8, 9, and 11, shocks are defined across a range of thresholds, and observations are classified into bins based on the value of the z-score. In robustness checks, we use the Standardized Precipitation Evapotranspiration Index (SPEI), which integrates evapotranspiration into the SPI.

A strong set of fixed effects and time trends is included. It follows best practices in the literature: grid cell fixed effects (γ_i), which control for time invariant and local characteristics that may affect economic growth; year fixed effects (φ_t), which control for changes in global patterns of economic growth; and country-specific time trends ($\mu_{c \times t}$), which account for country- specific trends in droughts and economic growth. Because weather variables tend to be correlated over time in the same location, we also include a vector X_{it}, which accounts for a quadratic in temperature to account for the well-established response of the overall economy to temperature increases. The rich set of fixed effects and controls in this specification isolates localized and unexpected fluctuations in shocks, facilitating causal inference, and is necessary to isolate the impact of exogenous changes in droughts on economic growth. Similar approaches have been used in previous climate and weather impact studies, such as Burke and Tanutama (2019); Callahan and Mankin (2022); and Damania, Desbureaux, and Zaveri (2020). Standard errors are clustered at the Administrative 1 level (one level below country, such as a state in the United States) to account for spatial and serial correlation. We test the robustness of the results through additional tests for spatial autocorrelation and use Driscoll-Kraay standard errors to account for spatial and temporal dependence (up to two lags of autocorrelation). Following other literature, we weight observations based on grid cell population. Because observations corresponding to grids with higher population have smaller variance, population weighting in the grid cell regressions accounts for heteroscedasticity and yields more efficient estimates (Damania, Desbureaux, and Zaveri 2020; Solon et al. 2015).

This baseline regression is modified to estimate heterogenous effects. Estimations on whether wealth and economic composition affect the relationship between droughts and economic growth are based on the World Bank income group classifications; grid cells are divided into those located in developing countries, which include low-, lower-middle-, and upper-middle-income countries, and high-income countries. To estimate whether climate endowments affect the relationship between droughts and economic growth, the Global Aridity Index and Potential Evapotranspiration Climate Database (Trabucco and Zomer 2019) is used to differentiate grid cells based on their aridity.

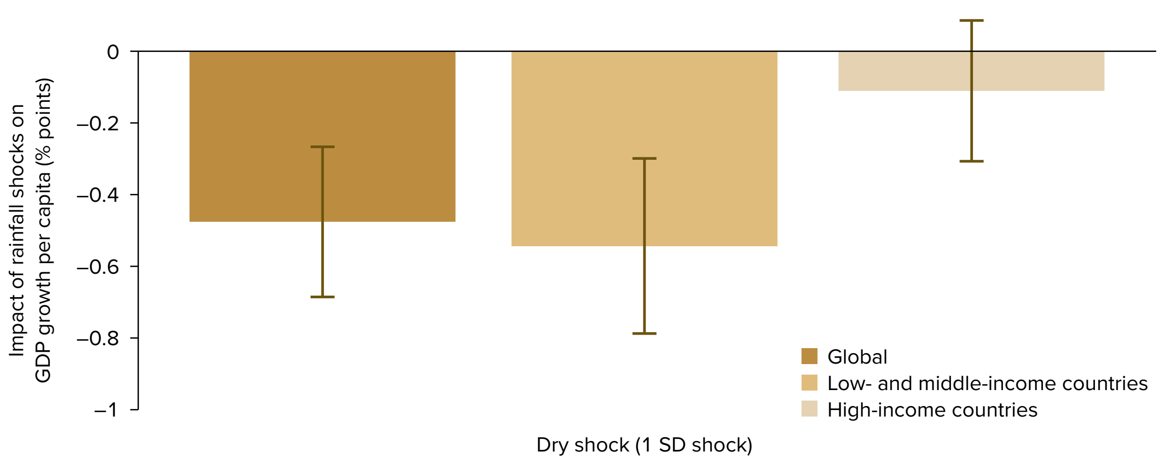
To estimate how antecedent conditions affect the relationship, the analysis calculates how much rainfall has deviated from long-run averages in the three years prior to the shock by summing z-scores over the three-year period. If there were significant rainfall deficits, these deficits would stack, and the cumulative z-score calculation would record a very deep three-year water deficit. This cumulative z-score is interacted with the main dry shock variables in the regression to assess whether wetter or drier conditions prior to a dry shock determines its impact on growth. The coefficients from these regression models are used to calculate the cumulative mean annual losses of GDP per capita growth due to a 1 SD dry shock at a fine disaggregated scale on a map. To investigate the role of forests in influencing antecedent conditions, past local and upstream share of forest cover is measured using satellite data from the European Space Agency. High forested areas denote places where the forest area is more than the 50th percentile of the forest distribution among all grid cells in each country.

Results

How have rainfall shocks affected the macroeconomy over time? This paper provides a comprehensive assessment of changes in GDP per capita growth resulting from rainfall shocks. It finds that dry shocks and their increasing severity reduce macroeconomic growth rates, with impacts that are heterogenous and vary with geography and development levels. Results are presented at a very high degree of spatial disaggregation using evidence of impacts from the past 25 years. Data are disaggregated into 60,958 subnational regions at the level of 0.5-degree grid cells (approximately 56 kilometers × 56 kilometers at the equator) across 82 countries. Analyzing impacts at a disaggregated spatial scale is crucial. Because rainfall varies dramatically across space, analysis at coarse resolutions, such as at country or state levels, cannot capture the complexities of local rainfall events. Box 2 provides an intuitive explanation on why such spatial disaggregation is necessary to avoid a statistical problem—the modifiable areal unit problem—which has distorted previous empirical work.

Results indicate that the impacts of dry shocks on economic growth are significant in some economies. Figure 3 shows that in the global sample, an additional dry shock, when rainfall is at least 1 SD *below* normal levels, reduces GDP per capita growth by 0.47 percentag e points on average. A 1 SD dry shock is a relatively rare event and normally can be expected to include around 15 of the driest episodes in a century. A 2 SD dry shock is an even rarer event and includes the driest 2.5 years in a century. Such dry episodes that ought to be intermittent are occurring more frequently. However, there is considerable heterogeneity across countries and even within countries.

Figure 3 Marginal Impact of Dry Rainfall Shocks on GDP per Capita Growth, by Development Level, 1991–2014



Source: World Bank.

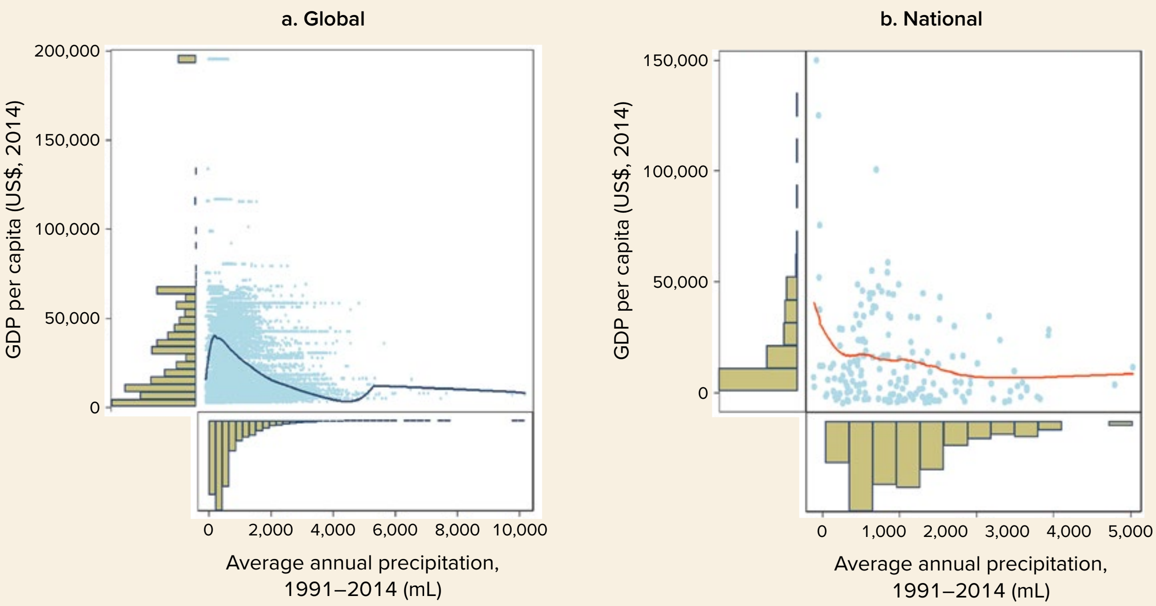
Note: GDP = gross domestic product: SD = standard deviation.

Box 2 Rainfall and Spatial Variability

Rainfall and water availability exhibit spatial variability that is considerably higher than that of temperature. For instance, one part of a country can often be undergoing a drought while another has abundant water. Indeed, the wettest areas in Alaska (4,880 milliliters per year) received 4,830 milliliters more precipitation on average per year between 1990 and 2014 than the Mojave Desert (52 milliliters per year). Temperature also varies in countries (for example, a 40°C difference between the coldest parts of Alaska and Miami, Florida); but globally, the within-country variation is twice as large for precipitation than it is for temperature. This implies that national-level averages conceal much variation and, hence, generate results that do not represent reality. For instance, averaging rainfall in the Mojave Desert with Alaska's generates a meaningless, unrepresentative statistic.

At the smallest spatial resolution available (0.5 degrees), there is an inverted U-shape (concave) relationship between precipitation and GDP per capita growth. Rainfall increases total economic productivity until it peaks, beyond which the marginal economic return declines with additional rainfall. Panel a of figure B2.1 plots the average cell-level precipitation (0.5 degrees) between 1991 and 2014 against the level of GDP per capita observed in 2014 (y-axis). Precipitation and GDP per capita follows an inverted U-shape. Up to a level of 500 milliliters to 700 milliliters of precipitation, an additional drop of rainfall is correlated with a higher level of GDP per capita. The relationship then turns negative. Consider aggregating all of this data to the national level. Panel b of figure B2.1 shows the same plot but with data at the national level. The relation between rainfall and GDP has vanished. The results suggest the need for spatial disaggregation to capture local heterogeneity.

Figure B2.1 Average Annual Precipitation, 1991–2014, and GDP per Capita, 2014



Source: Damania, Desbureaux, and Zaveri 2020.

Note: Solid lines represent the non-parametric correlation between weather variables and GDP using local weighted scatterplot smoothing.

Low-income countries and middle-income countries are considerably more vulnerable to dry shocks than are higher-income countries. Figure 3 shows that the adverse effects of an additional dry shock are heavily concentrated in developing countries. An additional dry shock reduces GDP per capita growth by 0.54 percentage points in low- and middle-income countries, while in high-income countries, impacts of an additional 1 SD dry shock are small and statistically insignificant.

The adverse effects on economic growth are sharper in agriculture-dominated areas of the developing world. The higher losses reflect these countries' greater dependence on agriculture, which is the sector most affected by rainfall. This is illustrated in figure 4, where grid cells that contain a larger amount of cropland are more sensitive to dry shocks. An implication is that much, but not all, of the variation in GDP per capita growth because of dry shocks in this sample is a consequence of the effects on agriculture.

Impacts are also determined by the availability of soil moisture when a dry shock occurs. Figure 5 illustrates that green water (soil moisture) matters for aggregate impacts. If a cell experiences high rainfall in the previous three years, the GDP growth impacts of a dry shock are considerably diminished because of higher initial soil moisture conditions. As the degree of wetness in previous years rises, adequate soil moisture can neutralize and possibly even overturn the harmful impacts from a dry shock in some grid cells. Conversely, consecutive dry years have the opposite effect and substantially amplify the adverse growth impacts of a dry shock. Recent scientific assessments find that the Earth has crossed the safe planetary boundary for green water (Wang-Erlandsson et al. 2022). These results indicate that the consequences are immediate and economically significant.

Figure 4 Marginal Impact of Dry Rainfall Shocks on GDP per Capita Growth, by Cropland Distribution, Low- and Middle-Income Countries Sample, 1991–2014

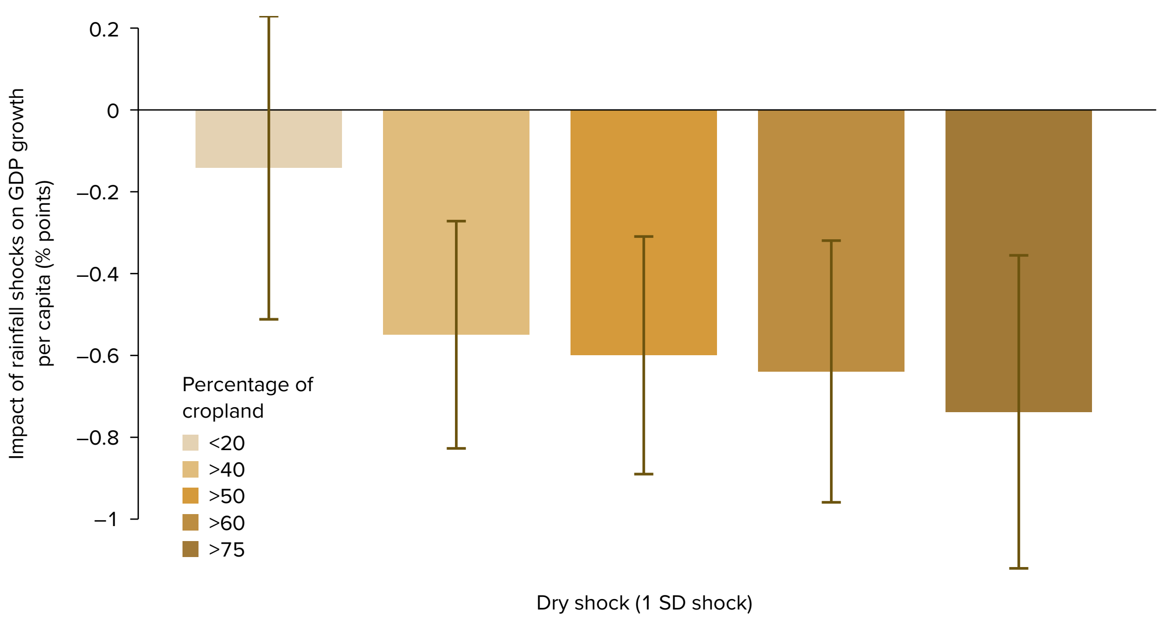
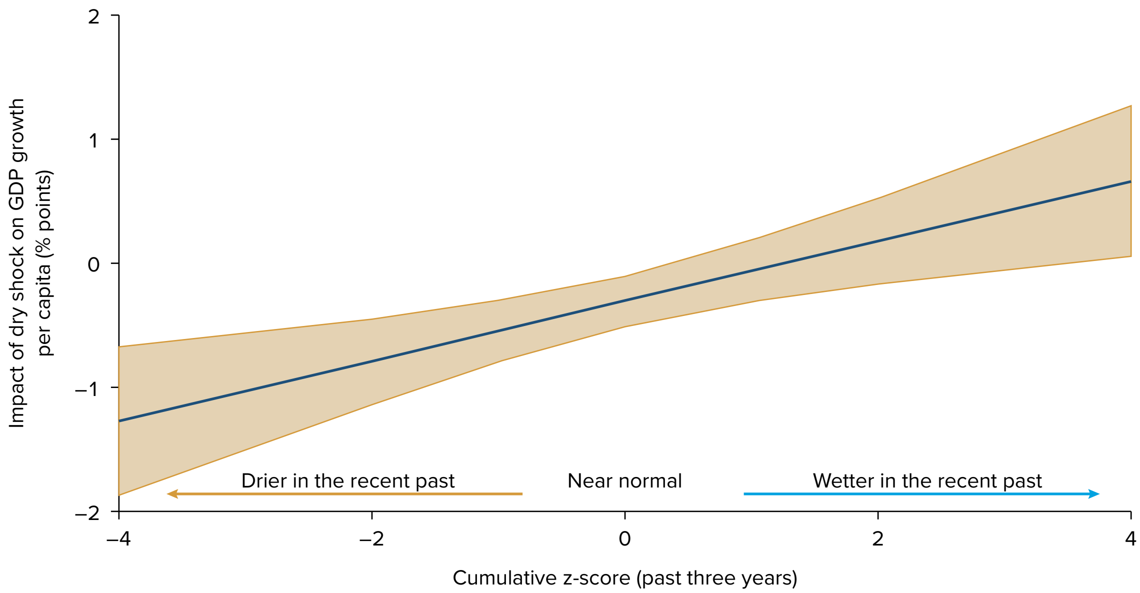


Figure 5 Marginal Impact of Dry Rainfall Shocks on GDP per Capita Growth, by Antecedent Conditions, Low- and Middle-Income Countries Sample, 1991–2014

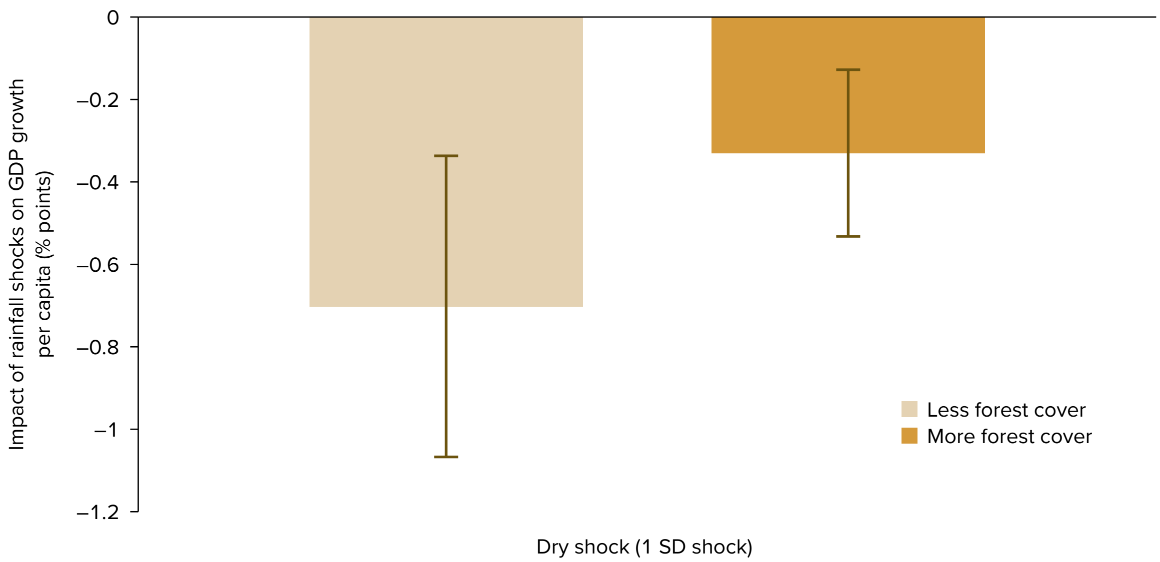


Source: World Bank.

Note: Figure shows impact of a 1 SD dry shock when the grid cell experiences rainfall that is lower than the long-run annual mean for the grid cell by at least 1 SD (see box 1 for more details). Cumulative z-score reflects antecedent conditions of past three years. GDP = gross domestic product; SD = standard deviation.

Healthy forests and landscapes are one of the key channels through which green water is maintained. Forests and trees add *moisture to the air* through transpiration and evaporation of water. The atmospheric water vapor passing over forests, in turn, can influence local and regional rainfall (Grosset, Papp, and Taylor 2023; Smith, Baker, and Spracklen 2023; Rockstrom et al., 2023). At the same time forests influence *moisture in the soil*. Across local watersheds and even thousands of miles away, forests can alter the movement and availability of water by regulating flow, absorbing water when it is plentiful, and releasing it when it is scarce (Miller, Mansourian, and Wildburger 2020). The dense canopy of trees provides a natural umbrella that traps rainwater, slowing the pace of rain and allowing it to enter the soil and thence to the ground below. Forest roots act as natural sponges, absorbing water and increasing the amount of water that can enter the earth, adding to soil moisture and recharging groundwater. Over time, forests slowly release that water, thus moderating downstream flows by lowering flooding, while improving dry season flow. Forests—especially fast-growing young plantations—may use more water than older, mixed, or natural forests and therefore reduce downstream freshwater availability. However, with proper management, forests, especially native forests, can help enhance the resilience of water supplies (Miller, Mansourian, and Wildburger 2020). Figures 6 and 7 show that higher local and upstream forest cover can help buffer the growth impacts of dry shocks by almost half.

Figure 6 Marginal Impact of Dry Rainfall Shocks on GDP per Capita Growth, by Local Forest Cover, Low- and Middle-Income Countries Sample, 1991–2014



Source: World Bank.

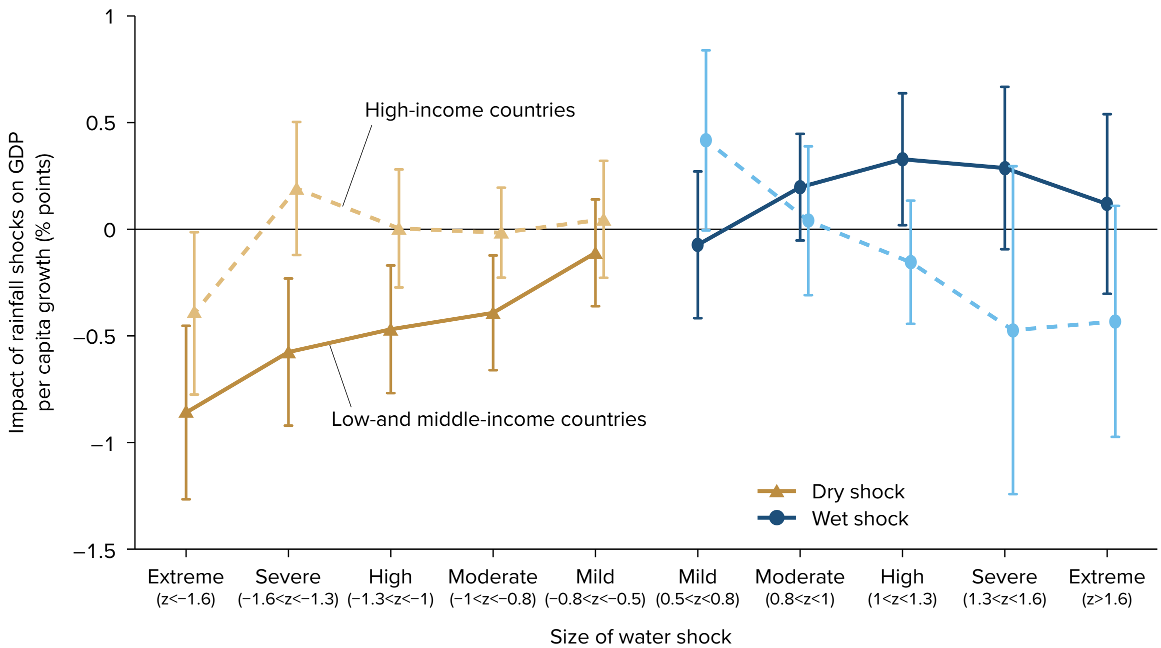
Note: GDP = gross domestic product; SD = standard deviation.

Figure 7 Marginal Impact of Dry Rainfall Shocks on GDP per Capita Growth, by Upstream Forest Cover, Low- and Middle-Income Countries Sample, 1991–2014

Source: World Bank.

Note: GDP = gross domestic product; SD = standard deviation.

Figure 8 Marginal Impact of Drought Severity on GDP per Capita Growth, Various Bins, Low- and Middle-Income vs. High-Income Countries Sample, 1991–2014



Source: World Bank.

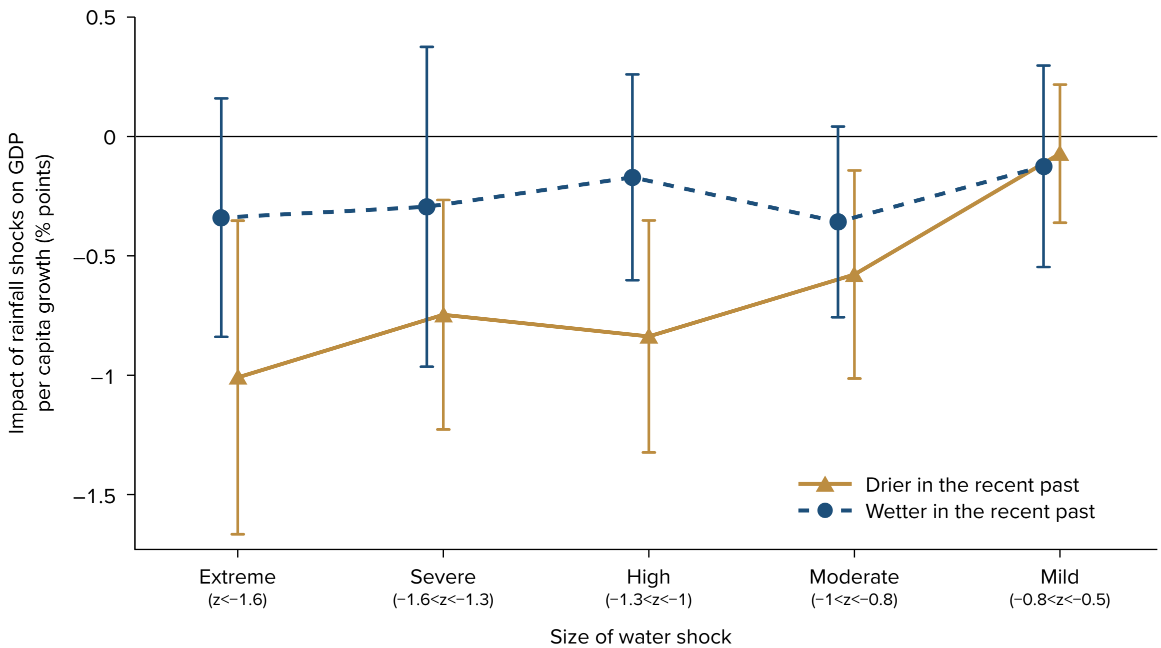
Note: GDP = gross domestic product.

Unsurprisingly, as the severity of the dry shock increases, so too does the impact on GDP growth. Compared to normal conditions, moderate drought reduces growth in the developing country sample by about 0.39 percentage points, and extreme drought reduces growth by about 0.85 percentage points (figure 8). Compared with an average growth rate of 2.19 percent over the time period of the sample, this implies that even moderate shocks can send impacted areas into a growth slump. In high-income countries, only extreme droughts have adverse GDP impacts, reducing growth by about 0.30 percentage points, a little less than half the impact felt in the developing sample for the same intensity of drought.

Figure 9 highlights the significance of green water (soil moisture) in mitigating GDP growth losses for different levels of dry shock severity levels. Adequate soil moisture's powerful buffering impact can halve the adverse growth effects of an extreme dry shock, rendering these statistically insignificant. The buffering benefits of wet prior conditions increase with the magnitude of the dry shock. This might suggest investments in green water could be a cost-effective and underrecognized way to build greater resilience to dry rainfall shocks.

Figure 10 shows that more forest cover might be one of the key channels through which these impacts manifest. This highlights the importance of halting forest loss to support green water functioning and climate resilience. It shows that the presence of tree cover mitigates the adverse impacts of droughts on per capita GDP growth.

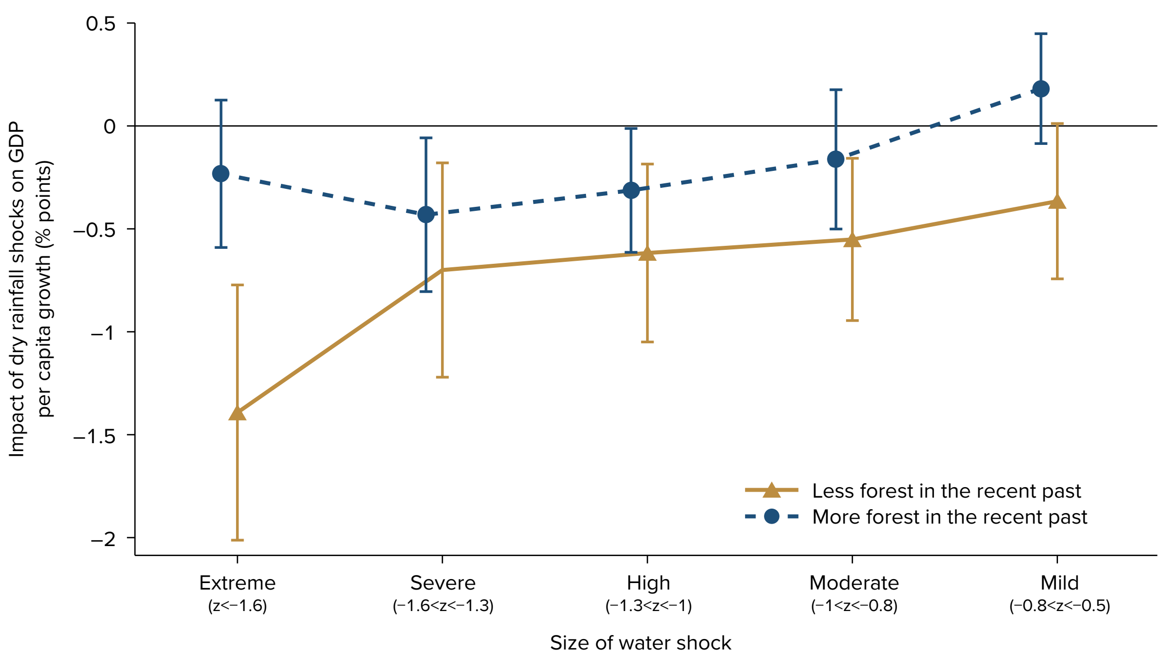
Figure 9 Marginal Impact of Drought Severity on GDP per Capita Growth, Antecedent Conditions, Low- and Middle-Income Countries Sample, 1991–2014



Source: World Bank.

Note: GDP = gross domestic product.

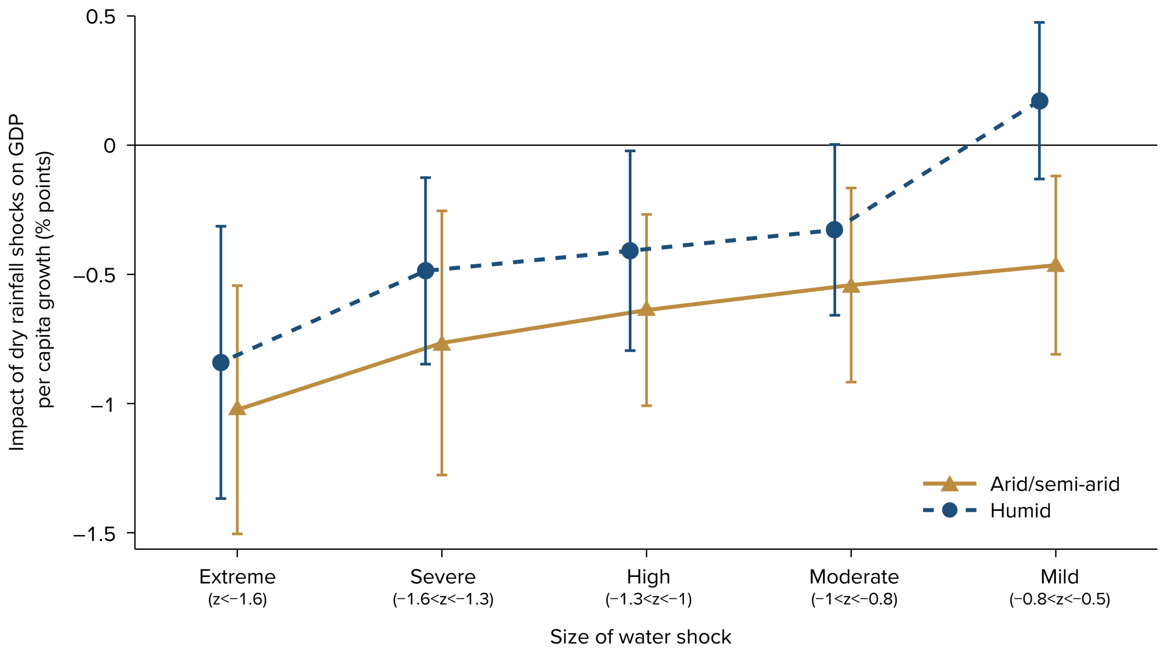
Figure 10 Marginal Impact of Drought Severity on GDP per Capita Growth, Forest Cover Conditions, Low- and Middle-Income Countries Sample, 1991–2014



Source: World Bank.

Note: GDP = gross domestic product.

Figure 11 Marginal Impact of Drought Severity on GDP per Capita Growth, Arid and Semi-Arid vs. Humid Regions, Low- and Middle-Income Countries Sample, 1991–2014



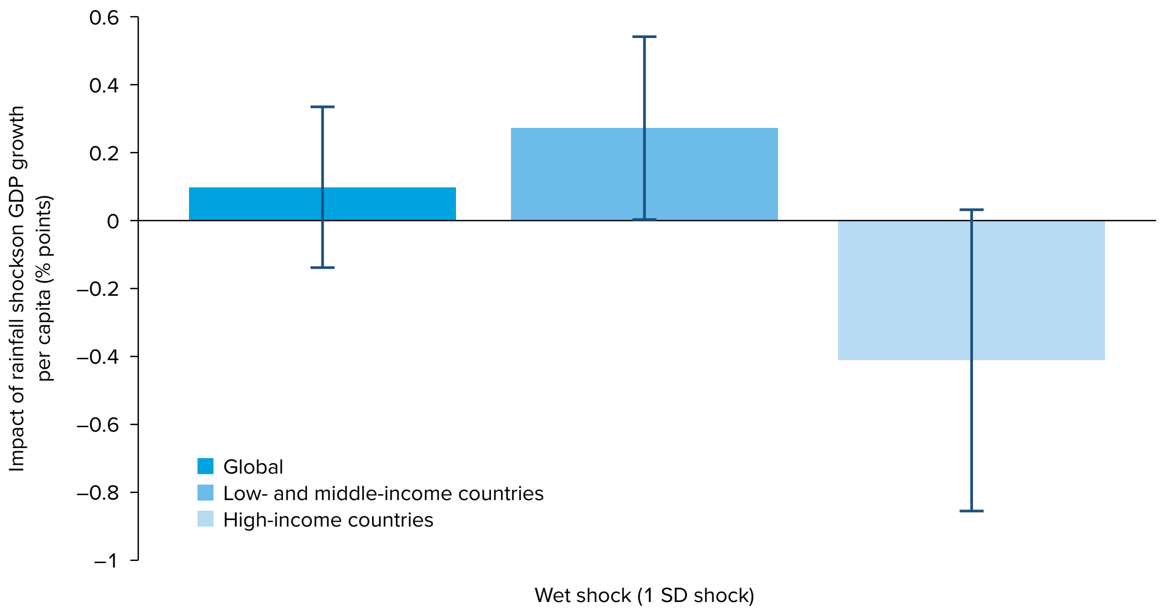
Source: World Bank.

Note: GDP = gross domestic product.

Geography also matters and the sensitivity to dry shocks is greater in arid and semi-arid regions than elsewhere (figure 11). This is likely due to synergistic factors that increase vulnerability. In general, arid areas are less suitable for agriculture and more vulnerable to dry episodes that induce crop stress. Lower levels of development also limit investments to build resilience in rainfall-sensitive sectors such as agriculture and diversify livelihoods away from these sectors. These factors heighten vulnerability and create a vicious cycle of vulnerability and poverty.

The results consistently reveal that wet shocks have limited or no discernable impact on GDP growth. Figure 12 shows that wet shocks have a slightly positive or no impact in developing countries but appear to be harmful in high-income countries. (See also Kotz, Levermann, and Wenz [2022] for a similar finding.) Because most developing countries are in drier parts of the world, above-average rainfall is typically associated with increases in crop yields and may act as a buffer for future dry shocks by storing soil moisture in the root zone (figure 12). In high-income countries, the negative effects of wet shocks reflect the effects of floods on infrastructure and urban assets. Improvements in disaster risk management and relief also mean that recovery from floods is rapid in developed economies, with limited observable effect on economic activity (Kocornik-Mina et al. 2020; World Bank 2021).

Figure 12 Marginal Impact of Wet Rainfall Shocks on GDP per Capita Growth, by Development Level, 1991–2014



Source: World Bank.

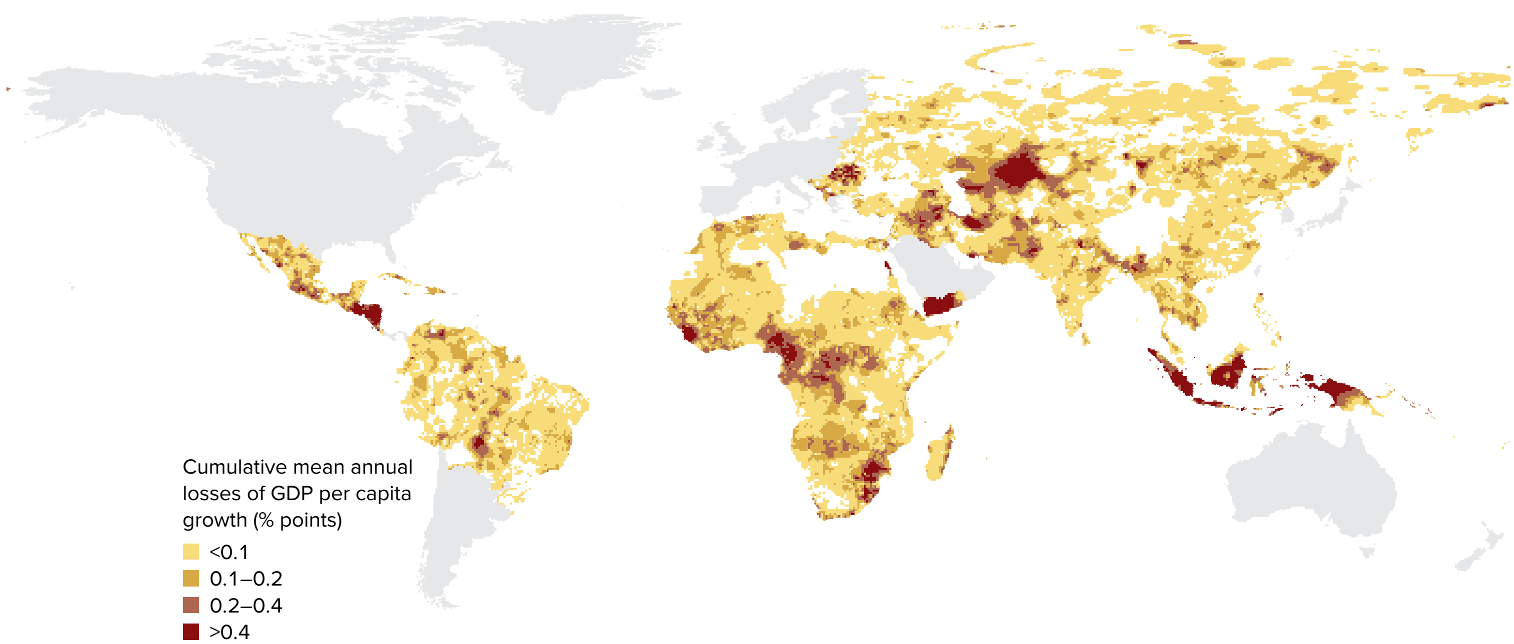
Note: GDP = gross domestic product; SD = standard deviation.

The significance of these findings has been widely overlooked in discussions of macroeconomic policy. Overall, these results demonstrate that it is the low- and middle-income countries in arid areas that sustain the highest relative losses. Thus, droughts can translate into a widened poor-rich gap. The 2022 United Nations (UN) Global Assessment Report on Disaster Risk Reduction looks at all types of disasters, from rapid onset events like typhoons, floods, and earthquakes to other events like droughts, saltwater intrusion, and air pollution. It finds that poorer countries lose on average 0.8–1 percent of their GDP growth per capita to disasters per year, compared to 0.1–0.3 percent in higher-income countries. This paper finds similar magnitudes of drought impacts on GDP growth using state-of-the-art statistical techniques widely used in the literature, which suggests that less visible droughts deserve greater attention among policy makers.

Atlas of Impacts

The macro-criticality of water varies considerably around the world. To provide a sense of magnitudes, it is instructive to use the estimates used in figure 5 to calculate the cumulative mean annual losses in GDP per capita growth in each grid cell. Map 2 shows that these impacts are unevenly distributed around the globe and vary significantly across and within countries. The patterns highlight the disproportionate losses in developing countries and suggest the need for urgency in increasing adaptive capacity in the poorest parts of the world. The estimates in map 2 can help policy makers prioritize and spatially target interventions to areas of greatest growth impacts. With limited fiscal space, such information is particularly valuable in enabling more efficient responses to the increasing threats from climate change.

Map 2 Atlas of the Economic Costs of Droughts, 1994–2014



Source: World Bank.

Policy Implications and Way Forward

These findings have several implications for development practitioners. First, they are a starting point for understanding and appreciating the vulnerability to drought within and between countries. The spatial differences in economic impacts need unpacking to gain a more nuanced understanding toward the drivers of these vulnerabilities and how droughts manifest in a particular economy.

Second, they send a clear message that the developing world has been ill-prepared for managing the risks and impacts of droughts over the past few decades. Climate change is expected to lead to greater drought severity in many regions. Without significant improvements to how policy makers manage droughts, the world is on a path to even greater losses in economic growth and development gains due to these prolonged dry shocks.

And third, the results highlight the significance of green water (soil moisture) in mitigating drought impacts, which has been overlooked in economic deliberations. It highlights the need for stewardship of forests and other natural capital that affect the hydrological cycle but are seldom associated with the growth impacts of droughts. As the climate heats up, many regions will face less predictable local rain. There is already evidence that there is a drying trend across much of the developing world. This makes the dependable waters of soils, groundwater and rivers, and the well-managed forests that nurture them frontline climate warriors.

Countries need to proactively invest to address the vulnerabilities through upgrades in information systems, institutions, and infrastructure that build drought resilience. There are several specific ways in which the World Bank and other development partners can support countries in addressing these challenges and needs.

Foremost is to support the development, implementation, and integration of early warning systems in countries and regions where they are lacking or insufficient. Governments often monitor drought by a single indicator, such as the SPI or soil moisture levels, and the indicator often changes depending on the sector or ministry. This creates competing definitions and understanding of the country's drought situation. Thus, the lack of triangulation across indicators for monitoring droughts and inconsistent definitions in a given country context result in inaccuracies and, ultimately, inaction. Integrated and consistent monitoring programs that more comprehensively and objectively define drought can help countries get ahead of a drought. These programs can also link drought severity designations with predetermined actions that are triggered as a drought unfolds. The World Bank can develop similar internal protocols for monitoring drought situations worldwide so the institution is better positioned to offer timelier and less reactive support to clients as drought situations worsen in a given location.

There is a need for more regular and proactive evaluation of the vulnerabilities and impacts, as well as determining countries' drought preparedness capabilities. With floods, tropical cyclones, earthquakes, and other types of natural disasters, the vulnerabilities, impacts, capabilities, and needs are often evaluated in the immediate wake of the event through the application of a postdisaster needs assessment (PDNA). Unfortunately, such exercises inadequately capture drought events. This is because of the slow onset nature of the event and the highly diffuse and cascading impacts that cross multiple sectors across space and time, among other reasons. Therefore, policy makers need to develop new diagnostic approaches that not only accommodate the unique nature of the hazard but also address the historical shortcomings of how countries have previously prepared or not for the impacts. The approaches need to encompass evaluation and inclusion of immediate response and recovery activities, and build a pipeline of longer-term investments to minimize risks in future drought events. Unlike a traditional PDNA, drought needs assessments (DNAs) would be done iteratively, not only during a drought crisis, and consider potential impacts from shifting drought hazard profiles due to climate change.

Conducting DNAs would help countries prioritize amid potential investments for bolstering drought resilience. Investment packages might include (a) upgrades to information systems, such as early warning systems; (b) infrastructure, such as storage, nature-based solutions, groundwater and managed aquifer recharge, desalination, water reuse and recycling, nonrevenue water reduction, irrigation schemes, or rainwater harvesting; (c) institutions, such as drought policy and legislation to codify roles and responsibilities and standing drought committees; and (d) risk financing mechanisms tailored to vulnerable groups in each country.

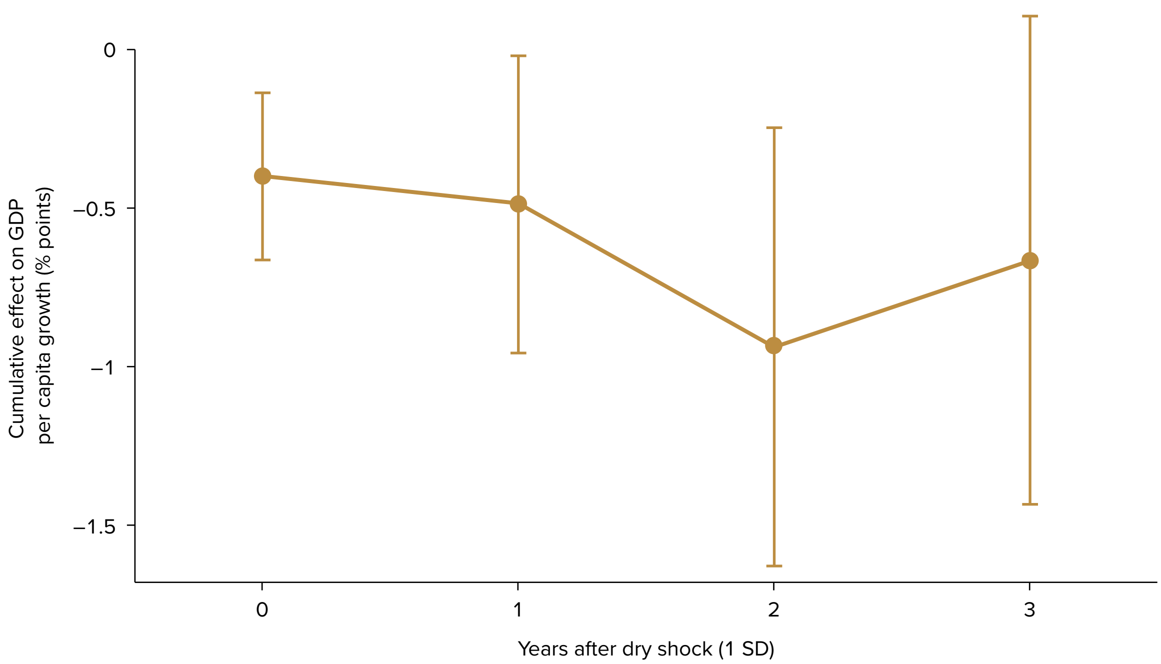
Managing through a drought efficiently, effectively, and equitably requires considerable investments in coordinated planning before a drought hits. These include short-term emergency planning and drought contingency planning at scales that define who does what and when as a drought is unfolding. These actions would be triggered with the early warning system and associated drought protocols. Similarly, countries need strategic long-term planning efforts, including scenario planning, to identify the most robust set of measures for improving long-run drought resilience. The scales for these two sets of planning activities are manifold, and include utility, city or town, river basin, province, and national levels.

Appendix B provides two examples of recent or ongoing World Bank engagements that illustrate how Brazil and Eswatini have addressed these challenges and needs. However, there is considerably more work to do on this agenda. The World Bank is well-placed to help structure a more effective program around drought resilience-building that can be offered to clients in all regions around the world. This assistance can help countries avoid drought-induced poverty traps in the future.

Appendix A
Persistence of Impact

To determine whether the effects of dry shocks persist beyond the year in which they occur, a distributed lag model of the main regression specification is estimated. This model adds lags to the 1 SD dry shock to account for potential economic recovery. If shocks cause only a fall in the level of output, the year after an event would see increased growth as economies rebound to their pre-shock income trajectories. However, if shocks affect growth, then future years will not necessarily rebound. Therefore, if shocks affect the level of output but not its growth rate, then the contemporaneous and lagged effects should have opposite signs. The negative effect of a dry shock on output in a given year would be followed by a positive effect the following year as the economy rebounds. In this case, the cumulative effect converges to zero, a characteristic of level effects. However, if dry shocks affect the growth rate of output, then lagged effects would be zero or could have the same sign if the effects persist. Figure A.1 shows the cumulative impact of a 1 SD dry shock on GDP per capita growth and provides some evidence for persistent effects. The negative and statistically significant impact on GDP per capita growth appears to hold for two years after the dry shock.

Figure A.1 Cumulative Impact of a 1 SD Dry Shock on GDP per Capita Growth



Source: World Bank.

Note: GDP = gross domestic product; SD = standard deviation.

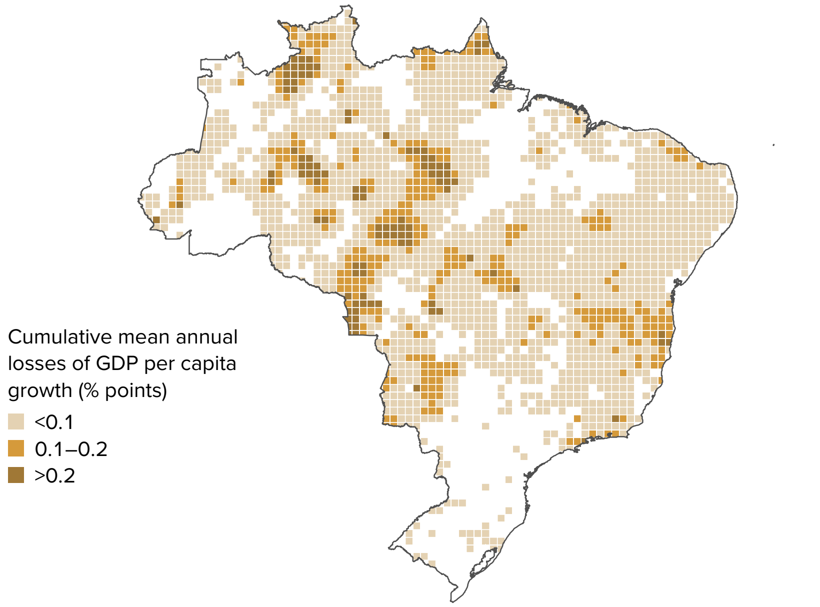
Appendix B
Examples of Recent and Ongoing World Bank Engagements in Drought Responses

Brazil

Map B.1 shows how the GDP impacts of drought vary considerably across Brazil. Northeast Brazil is predominantly semi-arid and historically prone to wide swings in climate variability, including prolonged droughts. It is also one of the poorest regions in the country. With the onset of the recent multiyear drought of 2012–15, the World Bank mobilized support to shift the paradigm on drought management in the region. As with most cases, the typical approach in Brazil had been to apply poorly planned and uncoordinated measures as the crisis unfolded. This inefficient and costly ad hoc approach was slow to respond to the needs and often failed to address the underlying drought vulnerabilities of the communities most affected by the droughts.

The first step toward a proactive approach was to develop and implement a drought monitor to categorize stages of drought severity. Previously, the accepted definition had been a qualitative understanding of drought (seca) or no drought. Under the new drought monitor, Monitor de Secas, five stages were demarcated using an evidence-based approach that provided a more objective understanding of when areas in the region were entering or exiting drought status. The effort was inspired by the U.S. Drought Monitor (USDM) and involved USDM experts and experienced officials from Mexico, which had recently implemented a similar drought monitor process. They developed the technical and institutional protocols for producing and sustaining a monthly drought map. The nine-state map was initially produced by three northeastern states with significant capacity in meteorology, climatology, and hydrology: Ceará, Pernambuco, and Bahia. Now 23 out of 26 states and the Federal District produce a monthly map. The joint ownership of the process is between the national water agency, Agência Nacional de Águas, and the states.

Map B.1 Cumulative Mean Annual Losses of GDP per Capita Growth, Brazil, 1994–2014



Source: World Bank.

The growth and sustainability of the Brazil Drought Monitor prove its effectiveness in helping governments to better mobilize and target resources as a drought unfolds. Developing preidentified actions triggered at different stages of a drought, or drought preparedness planning, was supported by the World Bank program during the 2012–15 period. This support helped to pilot drought preparedness plans across vulnerable sectors and scales of decision-making with respect to droughts in the Northeast; two cities and their water utilities, one river basin, one reservoir system, and one rainfed agricultural municipality. These plans have been expanded in many of these contexts and address vulnerabilities before, during, and after droughts have hit the region.

A final component was a post drought assessment of the costs and impacts to understand how expensive this reactive approach was for the region and country. The analysis quantified the budgetary costs of the policy responses, estimated to be close to US$4.5 billion. It also looked at the longer-term impacts on key sectors of the economy. For example, relative to normal levels, the drought resulted in a 13 percent loss in gross real value of agriculture output (De Nys, Engle, Magalhães 2016). These findings further justified the World Bank programs that supported the government's shift to a more proactive approach for managing future droughts.

Eswatini

The severe 2015–16 drought in Eswatini in Southern Africa resulted in significant negative impacts on livelihoods, decimating agricultural production and wiping out traditional forms of savings, especially in rural households. Roughly 620,000 people were forced to rely on food support or cash transfers for survival. It also wreaked havoc on flora and fauna, increased poverty, and forced workers to migrate into neighboring countries or economies.

The World Bank performed a disaster risk financing diagnostic to gain a more nuanced understanding of the economic impacts of the drought throughout the Eswatini economy. The drought cost the government 19 percent of its annual expenditure, equivalent to 7 percent of its GDP (World Bank 2022). It also found that droughts are not only the most severe natural hazard facing Eswatini but also the most frequent, which can be a devasting combination. These findings are consistent with the analysis of this paper, which flags Eswatini as having suffered significant impacts on per capita GDP growth rate over the past several decades.

World Bank support for building drought resilience was mobilized after the 2015–16 drought through the Eswatini Water Supply and Sanitation Access Project (EWSSAP). It aims to improve long-term management of water resources, investment planning, sustainability of water supply service provision, and community resilience to climate and disaster risks, especially drought. Similar to Brazil's government, the Eswatini government has relied on reactive response and external assistance to finance its interventions during drought crises. Addressing core vulnerabilities requires a more proactive approach that includes upgrades to infrastructure, institutions, and information systems.

The main infrastructure component under the project is a 65-kilometer main pipeline that carries treated water from one portion of the country to another, both in regions that have the least access to water supply and sanitation services and are particularly prone to droughts. During a given drought event, however, one area may be affected and the other to a lesser extent, or not at all. Therefore, the pipeline's design will consider allowing for flow reversibility to make the infrastructure and the communities that depend on it more resilient during times of drought.

Also integral to the EWSSAP are information systems and institutional strengthening activities. These include the development of a drought risk profile to give a more granular perspective of the communities and sectors most vulnerable to drought risks throughout the country. The project incorporates the operationalization of a drought monitor and early warning system, drawing from U.S. experience and expertise and recent efforts in Brazil. The monitoring approach in Eswatini relies on advancements in Earth observation data synthesis techniques to build a more automated process to produce a combined drought index (CDI) for Eswatini. The CDI includes process-related improvements that incorporate feedback mechanisms to validate drought impacts on the ground with the communities, which requires increased institutional support and coordination by the Eswatini National Disaster Management Agency (NDMA).

The NDMA is leading the development of drought contingency plans for all 14 towns and cities in Eswatini. The plans will include detailed vulnerability assessments and linkages with the CDI drought characterization to develop protocols that trigger actions when a drought hits. The project includes the development of a disaster risk financing strategy to identify and implement risk layering instruments and delivery mechanisms to better prepare the country for dry shocks and other disasters.

The country will stitch these elements and related efforts to build drought resilience over the past years, such as a national drought preparedness plan funded under UN auspices, to develop a national drought policy and legislation. This will codify and formalize roles, responsibilities, and processes for an ongoing and iterative approach to drought resilience, ultimately ensuring sustainability and longevity beyond the lifetime of the project.

Countries can do more to address drought risks before a drought crisis ensues. Even in the cases of World Bank support highlighted here, the support has come only during or after a drought emergency. While droughts provide windows of opportunity to improve countries' resilience to the next drought, the World Bank should assist countries to get ahead of the next drought crisis before it emerges. Thus, the analysis and findings in this paper regarding the economic impacts on per capita GDP growth rates represent an opportunity. They can stimulate dialogue with development partner governments on the significant costs of drought for their respective economies and bolster the case for prioritizing drought resilience building investments in infrastructure, institutions, and information systems.

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