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# Reduced burden of childhood diarrheal diseases through increased access to water and sanitation in India: A modeling analysis

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ABSTRACT

Each year, more than 300,000 children in India under the age of five years die from diarrheal diseases. Clean piped water and improved sanitation are known to be effective in reducing the mortality and morbidity burden of diarrhea but are not yet available to close to half of the Indian population. In this paper, we estimate the health benefits (reduced cases of diarrheal incidence and deaths averted) and economic benefits (measured by out-of-pocket treatment expenditure averted and value of insurance gained) of scaling up the coverage of piped water and improved sanitation among Indian households to a near-universal 95% level. We use IndiaSim, a previously validated, agent-based microsimulation platform to model disease progression and individual demographic and healthcare-seeking behavior in India, and use an iterative, stochastic procedure to simulate health and economic outcomes over time. We find that scaling up access to piped water and improved sanitation could avert 43,352 (95% uncertainty range [UR] 42,201–44,504) diarrheal episodes and 68 (95% UR 62–74) diarrheal deaths per 100,000 under-5 children per year, compared with the baseline. We estimate a saving of (in 2013 US$) $357,788 (95% $345,509–$370,067) in out-of-pocket diarrhea treatment expenditure, and $1646 (95% UR $1603–$1689) in incremental value of insurance per 100,000 under-5 children per year over baseline. The health and financial benefits are highly progressive, i.e. they reach poorer households more. Thus, scaling up access to piped water and improved sanitation can lead to large and equitable reductions in the burden of childhood diarrheal diseases in India.



## 1. Introduction

Each year, roughly 1.2 million children under the age of five years die in India (You et al., 2015). India accounts for 20% of the global burden of under-five deaths and is the single largest contributor to this burden (You et al., 2015). Diarrhea is among the leading causes of child death in India, claiming more than 300,000 lives (Liu et al., 2012; Parashar et al., 2003) and resulting in economic losses of $13 billion, or 1.5% of gross domestic product (GDP) per year (UNICEF, 2013). Of pathogens causing diarrheal disease, only rotavirus is currently vaccine-preventable; in India, it causes about 40% of all diarrhea hospitalizations, 2 million outpatient visits, and 113,000–153,000 child deaths per year (Kang et al., 2005; Morris et al., 2012; Tate et al., 2009). India has recently introduced a vaccine against rotavirus, but non-rotavirus diarrhea will continue to be an important cause of morbidity and mortality (PIB, 2014a).

Access to clean drinking water, sanitation, and hygiene can reduce the incidence of non-rotavirus diarrhea in low- and middle-income countries (Arnold and Colford, 2007; Cairncross et al., 2010; Esrey et al., 1985; Fewtrell et al., 2005; Fink et al., 2011). Using household survey data from 70 developing countries over the period of 1986–2007, Fink et al. (2011) found that access to improved sanitation was associated with a 13% reduced odds of childhood diarrhea incidence and 27% reduced odds of stunting. The authors also showed that access to high quality water was

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associated with 8% lower odds of diarrhea and 9% lower odds of stunting. In a meta-analysis of 46 studies across developing countries, Fewtrell et al. (2005) found that access to improved water supply and sanitation reduced the risk of diarrhea morbidity in overall population by 25% and 32%, respectively, while access to water and sanitation together reduced the risk by 33%.

In India, Jalan and Ravallion (2003) used nationally representative household survey data from the National Council of Applied Economic Research of India (1993–1994) and employed quasi-experimental matching methods to find that access to piped water reduced the prevalence of diarrhea among children by 17.4%. Similarly, Kumar and Vollmer (2013) used matching methods on the District Level Household Survey 2007–2008, another large nationally representative database, to find that children with access to improved sanitation were 16.9% less likely to contract diarrhea compared with similar children with no access.

The World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) recommend a seven-point plan that includes both prevention and treatment strategies for tackling childhood diarrhea (WHO/UNICEF, 2009). Three of these seven strategies are related to hygiene ("Promotion of handwashing with soap"), clean water ("Improved water supply quantity and quality, including treatment and safe storage of household water"), and sanitation ("Community-wide sanitation promotion").

The United Nations Millennium Development Goal (MDG) target 7c aimed to reduce by half "the proportion of the population without sustainable access to safe drinking-water and basic sanitation" across the world by 2015. Later, the goal was modified to consider "improved" drinking water, which included piped water, public tap water, tube wells and boreholes, protected wells, and protected spring and rainwater collection. The newly adopted United Nations Sustainable Development Goal number 6 has called for "universal and equitable access to safe and affordable drinking water" and "adequate and equitable sanitation and hygiene for all" by 2030 (UN, 2015).

According to the 2011 MDG report, more than 90% of Indian households now have access to improved drinking water (UNDP, 2011). However, the estimates are based on self-reported sources of drinking water and do not consider its actual quality. "Improved" drinking water may not necessarily be free from contaminants and pathogens (Bain et al., 2012). A recent study in urban India found that among households who reported using at least one method of water purification at home, more than 55% had fecal bacteria contamination in their drinking water (Jalan and Somanathan, 2008). Therefore, further improvements in access to clean water could reduce the burden of diarrheal diseases.

Although most Indian households have access to improved drinking water, close to half still lack access to basic sanitation (UNDP, 2011), and only 40% have access to "improved" sanitation (defined by WHO/UNICEF as certain types of flush, pit, or composting toilet) (WB, 2015; WHO and UNICEF, 2000). In 1999, India launched the "Total Sanitation Campaign," which built more than 64.3 million toilets by 2010, increasing sanitation coverage significantly over a decade (WB, 2010). The campaign, which cost approximately US$25 per household in 2009 (Kumar and Vollmer, 2013), focused on providing access to toilets and encouraging their use. It was expanded into a larger sanitation and public health program named the Swachh Bharat (Clean India) Mission in 2014, with a goal of providing universal access to sanitation by 2019. During 2014–2015, Swachh Bharat Mission has built 5.85 million new toilets across rural India (GoI, 2015).

In this study, we estimate the potential health and economic benefits of scaling up access to piped drinking water (for individual households or via public taps) and improved sanitation (flush or pit toilet) in India using IndiaSim, an agent-based microsimulation model that is based on a representative population. IndiaSim incorporates individual characteristics related to demographic and healthcare-seeking behavior, aggregate disease progression, and characteristics of the public healthcare delivery system (Megiddo et al., 2016, 2014a, 2014b; Nandi et al., 2016). We estimate the extent to which scaling up the combined coverage of piped water and improved sanitation to a near-universal, 95% level would reduce the health and economic burden of childhood diarrheal diseases. Health benefits are reflected by changes in incidence of diarrheal disease and deaths averted compared with a baseline of current coverage. Economic benefits are measured by changes in out-of-pocket expenditure for diarrheal disease treatment that is averted, and the extent of financial risk protection offered by the interventions.

## 2. Materials and methods

IndiaSim is programmed in C++11 standard and R version 3.2 (R Core Team, 2015). It is an iterative, stochastic model, where each model iteration represents a day (the time-step of the model). The model is organized in the form of geographical units, or patches. The urban and rural regions of Indian states and union territories are modeled as patches where each patch encompasses a set of households. These households consist of individuals representative of the respective rural or urban population in the given state.

### 2.1. Demographic data

The population data underlying IndiaSim come from the District Household Survey (DLHS-3) of 2007–2008 of India. DLHS-3 is a large-scale cross-sectional household survey of 720,000 households (more than 3.7 million individuals) from 601 districts in India that collected information on household socioeconomic characteristics, demographics, indicators of health-seeking behavior, and household access to water supply and sanitation. These data are publicly available and a separate ethics clearance was not required for this study. We populate the model utilizing demographic (age and gender) data of approximately 750,000 individuals from 131,000 randomly selected households from DLHS-3.

### 2.2. Income data

Households in IndiaSim are categorized by wealth quintile based on a composite index of asset ownership and living conditions (Filmer and Pritchett, 2001). We obtained data on GDP per capita at national and state levels from the World Bank and the Government of India (GoI, 2013; WB, 2015). We extrapolate the wealth index to create a distribution of per capita GDP (and five quintiles) across the population, which is then used to estimate the financial risk protection gained from the interventions.

### 2.3. Disease and treatment data

Individuals in IndiaSim are classified as healthy or suffering from diarrheal disease. They contract diarrheal pathogens based on a stochastic function of their characteristics (age and gender) and access to drinking water and sanitation. We use data from published studies to determine incidence by age (Fischer Walker et al., 2012) and case fatality rate (Black et al., 2014) of diarrheal diseases among the target population of under-five children, as shown in Table 1. In our model, access to piped water and improved sanitation only affects the incidence of diarrheal diseases. Case fatality, which is the likelihood of death for an incident case of diarrheal diseases, depends on the extent of dehydration and fluid loss from diarrhea (Bhandari et al., 1992; WHO, 2013). Since the effect of