TECHNICAL FOCUS PAPER

Forecasts of mortality and economic losses from poor water and sanitation in sub-Saharan Africa

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Contents

Acronyms

DHS	Demographic and Health Survey
DRC	Democratic Republic of the Congo
EBD	Environmental Burden of Disease Project
GDP	Gross domestic product
GWP	Global Water Partnership
JMP	Joint Monitoring Programme
MDG	Millennium Development Goals
MICS	Multiple Indicator Cluster Survey
ORS	Oral rehydration salts
PPP	Purchasing power parity
SSA	Sub-Saharan Africa
UNICEF	United Nations Children's Fund
UNPD	United Nations Population Division
VSL	Value of statistical life
WASH	Water, sanitation, and hygiene
WHO	World Health Organization
WHS	World Health Survey

Foreword

This paper presents country-level estimates of water, sanitation, and hygiene (WASH)-related mortality and economic losses associated with poor access to water and sanitation infrastructure in sub-Saharan Africa (SSA) from 1990 to 2050.

The paper examines the extent to which the changes that accompany economic growth will 'solve' water and sanitation problems in SSA and, if so, how long it will take. The simulations suggest that WASH-related mortality will continue to differ markedly across countries in sub-Saharan Africa. In many countries, expected economic growth alone will not be sufficient to eliminate WASH-related mortality or eliminate the economic losses associated with poor access to water and sanitation infrastructure by 2050. In other countries, WASH-related mortality will decline sharply, although the economic losses associated with the time spent collecting water are forecast to persist.

These findings suggest that in a subset of countries in sub-Saharan Africa, WASH-related investments should remain a priority for a few decades and require a long-term, sustained effort from both the international community and national governments.

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Dr Mohamed Ait-Kadi
Chair, GWP Technical Committee

1 Introduction

The magnitude of water and sanitation problems in developing countries is commonly described using two indicators: 1) coverage with ‘improved’ services; and 2) the number of deaths (or episodes of illness) due to water and sanitation-related diseases (UNICEF and WHO, 2015; Prüss-Üstün and Corvalan, 2006). These two indicators are obviously related: poor coverage leads to increased deaths and episodes of illness. Data on these two indicators are typically presented for current (‘status quo’) conditions. Sometimes analysts make comparisons between past coverage statistics and current conditions in order to show the rate of progress a country is making. Only rarely do analysts look ahead and attempt to forecast how these two indicators appear likely to change in the future, and to understand the economic consequences of these trends.

Our previous research has shown that, in fact, deaths and episodes of illness due to poor water and sanitation conditions are falling rapidly in most low- and middle-income countries and seem likely to continue to decline over the next few decades (Jeuland et al., 2013a). By 2050 WASH-related deaths will largely disappear in many parts of the developing world as economic growth and the demographic transition combine to expand coverage with improved water and sanitation services, and as better nutrition, health services, and housing all contribute to enhanced human well-being. On a regional basis, the primary exception to this good news is sub-Saharan Africa, one of only two regions[1] that did not achieve the Millennium Development Goals (MDGs) of halving the population without access to improved water sources and sanitation facilities by 2015 (UNICEF and WHO, 2015). Based on current demographic and economic growth projections, our previous forecasts, which were made in 2013, suggested that without targeted interventions, deaths due to WASH-related diseases and the economic losses associated with poor access to water and sanitation services will remain at high levels in many countries in sub-Saharan Africa.

At first glance this grim forecast for sub-Saharan Africa is surprising because some African countries have experienced record increases in economic growth over the past two decades (Radelet, 2010). Moreover, throughout the world (including in Africa), child mortality rates are declining and this decline is accelerating (Rajaratnam et al., 2010). In this paper we examine forecasts for WASH-related outcomes for sub-Saharan Africa in greater detail than in our previous work, looking carefully at the underlying dynamics behind the high mortality from WASH-related diseases in Africa, as well as the economic losses associated with poor access to water and sanitation services. We show that the regional averages for sub-Saharan Africa obscure important differences in WASH-related outcomes across countries.

Specifically, in this paper we use recent data to identify four groups of countries with different WASH-related mortality rate trajectories (Fig. 1). We then examine the economic losses associated with WASH-related mortality and morbidity as well as time spent collecting water. Countries in the first group currently have high WASH-related mortality rates, and our projections indicate that these rates will not decline much by 2050. Countries in the second group have moderate WASH-related mortality rates today compared with the rest of sub-Saharan Africa, but these moderate rates remain above those in the most comparable developing region – South Asia – by 2050. Countries in the third group start with moderate mortality rates, and these rates decline to negligible levels before 2050, as do those in South Asia. Countries in the fourth group start with low WASH-related mortality and these rates remain low throughout the simulation period.

[1] The other region is Oceania, which includes many small nations in the Pacific Islands.

Figure 1. Four groups of countries in sub-Saharan Africa on different WASH mortality trajectories

High mortality

Angola
Burkina Faso
Burundi
Central African Rep.
Chad
Dem. Rep. of Congo
Ethiopia
Guinea Bissau
Liberia
Mali
Niger
Sierra Leone
Somalia

Group 1

Moderate mortality, Slow decline

Benin
Cameroon
Comoros
Congo
Cote d'Ivore
Ghana
Guinea
Madagascar
Malawi
Mauritania
Mozambique
Nigeria
Rwanda
Sudan
Tanzania
Togo
Uganda
Zambia

Group 2

Moderate mortality, Rapid decline

Botswana
Eq. Guinea
Eritrea
Gambia
Kenya
Lesotho
Namibia
Senegal
Swaziland
Zimbabwe

Group 3

Low mortality

Cape Verde
Gabon
Mauritius
Seychelles
South Africa

Group 4

The projected trajectories of the sub-Saharan African countries in the third and fourth groups look much like those of the rest of the world (Jeuland et al., 2013a). For these countries, health-related economic losses and high mortality from poor water and sanitation conditions will soon be a thing of the past. Economic losses in these countries are forecast to remain low and consist primarily of losses associated with the time burden of water collection.[2] However, countries in the first and second groups need special focus from the WASH sector. Unfortunately, over our projection period to 2050, the majority of the population of sub-Saharan Africa will reside in countries that are not making sufficient progress to reduce WASH-related mortality and the economic losses associated with poor water and sanitation conditions.

In the next, second section of the paper we discuss the current, status quo conditions for countries in sub-Saharan Africa with respect to the variables of special interest for our analysis, including population, gross domestic product (GDP) per capita, urbanisation, water and sanitation coverage, WASH-related mortality, and time households spend collecting water. Our forecasts begin from these baseline conditions. The third section presents the population and economic growth projections for countries in sub-Saharan Africa. The fourth section summarises the modelling framework, highlighting the differences from our previous work forecasting global trends in WASH-related mortality and economic losses. The fifth section presents the results, including sensitivity analyses. In the sixth and final section we offer concluding observations.

2 This is because many countries in this group have substantial rural populations where households lack in-house piped connections and must collect water from sources outside the home (even improved sources).

2 Background

2.1 Water infrastructure coverage in sub-Saharan Africa

Water and sanitation infrastructure coverage in sub-Saharan Africa lags behind other regions of the world; our forecasts of future coverage thus start from a low baseline. The World Health Organization's and UNICEF's Joint Monitoring Programme (JMP) offers the most up-to-date, internally consistent set of indicators of the percentage of a country's population that has access to improved water and sanitation conditions. The most recent JMP data are for 2015.

The JMP publishes coverage statistics for two definitions of improved water services. The first is the simplest and most straightforward: "a piped water connection on the premises". This definition includes both yard taps (outdoor plumbing only) and piped water delivered inside the house (indoor plumbing). The second is "an improved water source that by the nature of its construction, adequately protects the source from outside contamination in particular with fecal matter" (UNICEF and WHO, 2015). The JMP classifies all of the following as improved sources: 1) piped into dwelling, plot, or yard; 2) public tap/standpipe; 3) tube well/borehole; 4) protected dug well; 5) protected spring; and 6) rainwater collection. "Piped into the dwelling, plot, or yard" (item no. 1) is one of the six types of improved sources, so the first definition is a subset of the second definition, i.e. reported coverage using the second definition will always be higher than reported coverage using the first definition.

Both definitions have problems. First, a piped water connection on the premises is counted as an improved source in both JMP definitions, but there is no assurance that the quality of water delivered to the household is potable. A piped connection that delivered unreliable, poor-quality water is still counted as an 'improved source'. Similarly for the second definition, water from the other types of improved sources may be contaminated, and the household will still be counted as having an improved source (Shaheed et al., 2014).

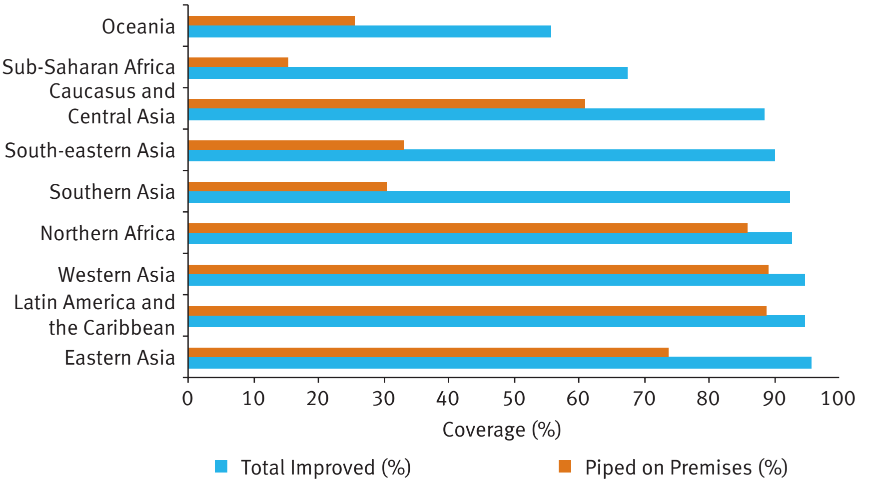
Second, water sources considered by the JMP to be 'unimproved' may, in fact, provide a household with potable water. For example, water vendors (both tanker trucks and distributing vendors) and bottled water are counted as 'unimproved sources', even though they may reliably supply a household with sufficient quantities of safe (high-quality) water.

Third, both definitions implicitly assume that a household only uses one source for its drinking water. This is often not true (Whittington et al., 2009b; Shaheed et al., 2014; Jeuland et al., 2014). Households may collect drinking water from both improved and unimproved sources, even if their 'improved' water source is a piped water connection on the premises. Despite these limitations, the JMP data on improved water coverage are the best available, and we rely upon them for our analysis. Appendix 1 presents the JMP country-level data for improved water coverage in 2015 in sub-Saharan Africa using both definitions of improved water services.[3]

Figure 2 shows the proportion of the population globally using improved water sources using the JMP's most inclusive definition of 'improved water services' (i.e. piped into dwelling, plot, or yard; public tap/standpipe; tube well/borehole; protected dug well; protected spring; and rainwater collection) as well as the proportion using the JMP's more restrictive definition ('piped

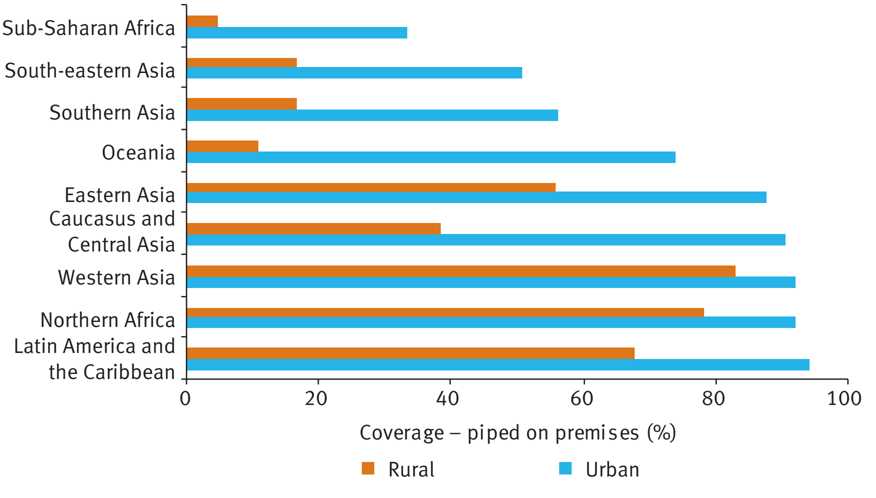
[3] In Jeuland et al. (2013a) the authors refer to piped water on the premises as 'piped' and the JMP's broader definition of improved sources as 'improved'.

Figure 2. Percentage of the population using improved drinking water sources and piped sources by MDG region



Source: UNICEF and WHO (2015).

Figure 3. Percentage of urban and rural population with water piped on premises by MDG region



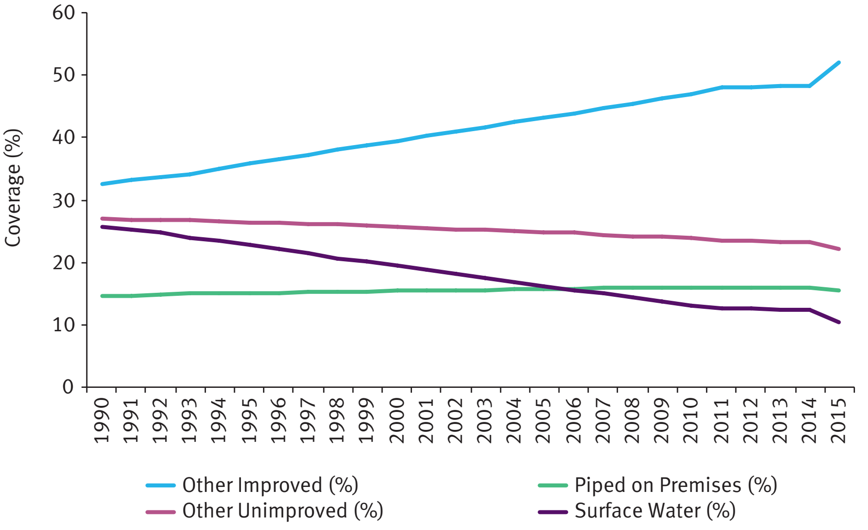
Source: UNICEF and WHO (2015).

water on the premises'). Figure 3 shows the proportion of the urban and rural population in different regions of the world with 'piped water on the premises'. In both rural and urban areas sub-Saharan Africa stands out as the region with the lowest level of access to improved water services.[4]

[4] Oceania also has very low levels of coverage, but this region is less readily comparable with the others because it contains many small island countries.

Figure 4 shows the changes in coverage in sub-Saharan Africa from 1990 to 2015 for four categories of water sources: 1) piped water on premises (improved); 2) other improved; 3) other unimproved; and 4) surface water source (unimproved). Coverage with 'other improved sources' grew substantially over the period, from 34 percent to over 50 percent. 'Piped water on premises' actually decreased over the 25-year period as a percentage of the population, although of course the population grew, and thus the total number of people with piped water increased. The big drop in percentage terms in unimproved sources occurred for 'surface water', which fell from 24 percent to approximately 10 percent.

Figure 4. Trends in access to drinking water sources in sub-Saharan Africa (1990–2015)



Source: UNICEF and WHO (2015).

2.2 WASH-related mortality rates in sub-Saharan Africa

No one really knows how many people die each year due to illnesses caused by poor water and sanitation conditions. Reports that 2 million children die annually due to WASH-related diseases are estimates, not precise counts. Many deaths in developing countries are not recorded in official statistics, and when deaths are recorded, the cause of death is often unknown. Global estimates of deaths due to WASH-related diseases are calculated using comparative risk methods (WHO, 2014). These methods use data on what is known about baseline water and sanitation conditions and the health risks of such conditions to infer likely episodes of illness and deaths. Data on baseline conditions, the causal relationship between conditions and episodes of illness, and the relationship between episodes and deaths (case fatality rates) are thus subject to significant uncertainty (Whittington et al., 2012). As a result, there is also considerable uncertainty surrounding the final estimates of mortality due to poor WASH conditions.

Walker et al. (2012, 2013) provide estimates of diarrhoea incidence in countries in sub-Saharan Africa and other regions of the world; the WHO (2004) has estimated WASH-related mortality data (Appendix 2). The estimates of diarrhoea incidence in sub-Saharan Africa are nearly 30 percent higher than in South Asia.[5] Yet, WASH-related mortality rates were estimated to be twice as high in 2004 in sub-Saharan Africa as in South Asia (WHO, 2004).[6]

It is a puzzle why WASH-related mortality rates are estimated to be so much higher in sub-Saharan Africa than in South Asia.[7] Both sub-Saharan Africa and South Asia have poor WASH conditions, high childhood malnutrition, and high levels of poverty. Moreover, the incidence of several infectious diseases (e.g. pneumonia and diarrhoeal diseases) is similar in sub-Saharan Africa and South Asia. But while sub-Saharan Africa had 23 percent of the global population of children under five years old in 2010, it had about 48 percent of estimated worldwide child deaths (UNPD, 2013; WHO, 2014).[8] In comparison, South Asia accounted for 27 percent of the worldwide population of children under five years old and had about 33 percent of child deaths (UNPD, 2013; WHO, 2014).

There are many factors that might explain the differences in WASH-related mortality in sub-Saharan Africa and South Asia, including differences in per capita income, healthcare access and quality, access to improved water and sanitation, demographics, fertility, and/or concomitant diseases. Sub-Saharan Africa, excluding South Africa, has the lowest indicators in the world for per capita incomes, headcount poverty, and child mortality (Klasen, 2007). In 2008, nearly 48 percent of the sub-Saharan Africa population lived on less than US$1.25 (PPP, purchasing power parity) per day, compared with 36 percent in South Asia. The proportion of the population living on less than US$2 (PPP) is nearly identical in the two world regions, 69 percent in sub-Saharan Africa compared with 71 percent in South Asia (World Bank, 2013). Yet, differences in income likely are not the full explanation.

Other possible explanations for the divergence in WASH-related mortality rates, and those from other infectious diseases across these regions, include differences in healthcare access and healthcare behaviours. Some protective behaviours include breastfeeding from age 0–2 months, vaccination (e.g. for rotavirus, which causes about 40 percent of diarrhoea hospital admissions among children under five), and adequate vitamin A and zinc (WHO Collaborative Study Team, 2000; DHS, 2003; Walker et al., 2013). Low immunization coverage might be a driver for the much higher mortality among children aged 1–4 years in sub-Saharan Africa (relative to a comparison of infant deaths, which dominate child mortality in other regions) (DHS, 2003). Klasen (2007) finds that immunization rates and sanitation access are associated with lower under-five mortality in sub-Saharan Africa.

Health-seeking behaviours for the sick may also be low in sub-Saharan Africa, perhaps partly as a result of the lower population density and lack of healthcare facilities. Living in rural areas is a major risk factor for child mortality (DHS, 2003), and the rural population is higher in sub-Saharan Africa than in other regions. In addition, there appears to be a relatively low rate of care-seeking in sub-Saharan Africa for diarrhoea – only 38 percent of cases receive oral rehydration therapy with continued feeding (DHS, 2003).[9] However, country-level rates of

5 Based on diarrhoea incidence data from Walker et al. (2012) and population data from UNPD (2014).

6 Diarrhoea incidence in 2010 in sub-Saharan Africa was 3.4 incidence-episodes per child-year, compared with 2.6 incidence-episodes in South Asia (Walker et al., 2012; UNPD, 2013). Based on WHO burden of disease data for 2004, WASH-related mortality in sub-Saharan Africa was 1.48 deaths per thousand population compared with 0.72 in South Asia.

7 Estimates in Rudan et al. (2008) of clinical pneumonia incidence in 2000 are similarly highest in South and Southeast Asia and Africa (0.36 and 0.33 episodes per child-year, respectively).

8 Pneumonia incidence for children under five is comparable in both regions, but mortality rates in sub-Saharan Africa also tended to be two to three times greater than in South Asia (Rudan et al., 2008).

9 Continued feeding as usual, as opposed to limiting food intake.

diarrhoea treatment (oral rehydration salts (ORS), homemade ORS remedies, or hospital admissions) do not seem to differ significantly between sub-Saharan Africa and South Asia for countries and years for which data are available (DHS, 2012).[10] Health-seeking behaviour may also differ between South Asia and sub-Saharan Africa because of social and cultural factors.

The quality of healthcare provision itself may also be worse in sub-Saharan Africa than in other world regions (Misselhorn and Harttgen, 2006). Several studies have investigated the significance of density of doctors, though their results are somewhat contradictory (Klasen, 2007; Anand and Bärninghausen, 2004). One comparative study of child mortality in South Asia and sub-Saharan Africa found that distance to health facilities was not significantly associated with mortality, but that usage of health services (prenatal care, mean number of vaccinations per child, and unassisted home births) was highly significant (Misselhorn and Harttgen, 2006). This result may however reflect underlying and unobserved differences that drive health-seeking behaviour rather than the effectiveness of healthcare itself.

The higher observed child mortality in sub-Saharan Africa might also be due to higher fertility and a stronger effect of high fertility on mortality risks than in other world regions (Klasen, 2006). Fertility-related risk factors related to higher child mortality include births in quick succession, as well as high birth orders, plus maternal characteristics such as mother's age, education, and experience as a caregiver (DHS, 2003).

There may also be differential impacts in the determinants and magnitude of child mortality across world regions that are due to non-linearities, interactions, and compounding of the types of effects listed above, or because of other health conditions (Misselhorn and Harttgen, 2006; Klasen, 2007). Other diseases, such as HIV and malaria, are known to exacerbate susceptibility to WASH-related diseases, and the incidence of these conditions is highest in sub-Saharan Africa. On the other hand, rates of childhood malnutrition are much higher in South Asia (Klasen, 2007). Consistent with this, anthropometric shortfall (height for age and weight for age) is almost 70 percent higher in South Asia compared with sub-Saharan Africa, even though South Asia has better healthcare provision, water and sanitation, and greater per capita calorie availability (WHO, 2005; Svedberg, 2002; Ramalingaswami et al., 1996).[11] One explanation for why children in South Asia tend to be malnourished and survive is that moderate stunting is a way of adapting to reduced calorie intake and is not necessarily related to poor health outcomes (Pelletier, 1994; Seckler, 1982). Alternatively, the widespread anthropometric shortfall in South Asia might be partially due to the use of a US-based anthropometric standard (Klasen, 2007).[12] If children in South Asia are genetically determined to be shorter and thinner than children in the US or sub-Saharan Africa, then undernutrition in South Asia would be overestimated (Klasen, 2006).

[10] Based on t-tests. Mean ORS usage in South Asia in 2005 was 46 percent (range 26 percent in India to 70 percent in Bangladesh), based on interpolated data from DHS (2012). In sub-Saharan Africa, mean ORS use was 31 percent (range 5.6 percent in Zimbabwe to 63 percent in Namibia). However, it should be emphasized that data for many countries in sub-Saharan Africa on diarrhoea treatment is not available from DHS. Among countries excluded are Angola, Cape Verde, Central African Republic, Gabon, Gambia, Guinea, Guinea Bissau, Somalia, and South Africa. For South Asia, data on the use of ORS and homemade ORS remedies are not available for Nepal or Afghanistan.

[11] While this nutrition gap between SA and SSA has narrowed somewhat from 1990 to 2000, it is still considerable, especially for wasting or underweight (Klasen, 2007).

[12] Applying this US standard globally assumes that there are no significant differences between child growth rates in different regions. However, if the growth potential of children in South Asia is less than children in the US, then this could lead to incorrect international comparisons of undernutrition. In 1994, a new international standard was developed by the WHO which was based on the growth of children in several regions of the world (WHO, 1999).

Some recent literature also argues that the striking differences in stunting between children in South Asia and sub-Saharan Africa (the so-called 'Asian enigma') can be almost fully explained by the much higher rates of open defecation in the former region, and particularly in India (Spears, 2013). Some of this work considers within-country differences in sanitation and stunting in India to bolster the argument on this connection, finding that 35–55 percent of the difference in stunting across districts can be explained by differences in open defecation, after controlling for socio-economic status, maternal education, and calorie availability (Spears et al., 2013). In fact, over half of people in India practise open defecation, in contrast to much lower rates (~25 percent) across sub-Saharan Africa.

The role that diarrhoeal illness plays in malnutrition has long been recognised (Checkley et al., 2008), yet the consensus in the literature has generally been that its contribution is modest, perhaps causing 4 percent of stunting (Bhutta et al., 2008). More recently, however, the public health literature has drawn attention to a condition known as tropical enteropathy, a subclinical disorder of the small intestine that perhaps better explains the connection between sanitation and hygiene and undernutrition (Humphrey, 2009). This literature uses evidence from long-term studies to suggest that the primary causal pathway from poor sanitation and hygiene to undernutrition may be through tropical enteropathy rather than diarrhoea (Lunn et al., 1991; Campbell et al., 2003). If this is true, then poor sanitation may explain the unexpected differences in stunting in India versus sub-Saharan Africa while explaining little about the mortality gradient from diarrhoea (which might instead relate to factors such as differential prevalence of other deadly infectious diseases, immunisation rates, or health-seeking behaviours discussed above). There may also be a connection between population density and environmental contamination by faeces, and therefore tropical enteropathy.

Finally, the divergence in WASH mortality between sub-Saharan Africa and South Asia may be due to measurement error. The WHO cautions that estimates for different years are not directly comparable.[13] There is also evidence of data discrepancies in the WHO's burden of disease estimates. For example, the data for India indicate many more deaths from diarrhoea in 2008 relative to 2002 and 2004, but the large increase in reported fatality rates occurs among adults, which seems unlikely (Jeuland et al., 2013a). Similarly, countries may differ markedly with respect to the quality of data collection, analysis, and reporting (Jerven, 2013).

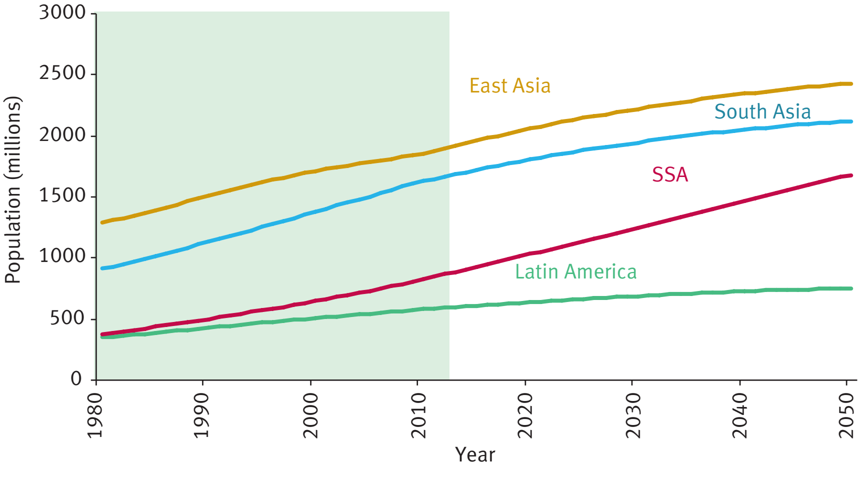
Despite these unresolved questions about the underlying determinants of the sub-Saharan WASH-related mortality estimates, for the purposes of our analysis, we use the WHO mortality estimates in our forecasting model. However, just as with the improved water coverage estimates, we emphasise that there remains considerable uncertainty about their accuracy.

[13] Estimates for different years are not directly comparable because they include: 1) differing vital registration data; 2) different sources of epidemiological data for specific causes; and 3) information on child and adult mortality that varies by year in countries lacking good death registration data.

3 Baseline economic growth and population forecasts

Given the differences in WASH mortality in South Asia and sub-Saharan Africa discussed above, we now examine projections for economic growth, population, and urbanisation in these and other regions. Figure 5 shows population projections for sub-Saharan Africa and other regions. While the population in other regions is projected to begin to level off by 2050, the population in sub-Saharan Africa is projected to continue to rise. This increasing trend in population is reflected in the projected population of four large countries in the region: South Africa, Kenya, Nigeria, and the Democratic Republic of the Congo (DRC) (Fig. 6). Fifty percent of the population of sub-Saharan Africa is projected to live in urban areas by 2030 (Fig. 7). This level of urbanisation is reached well after Latin America and East Asia, but before South Asia.

Figure 5. Population estimates from 1980 to 2050 for four regions

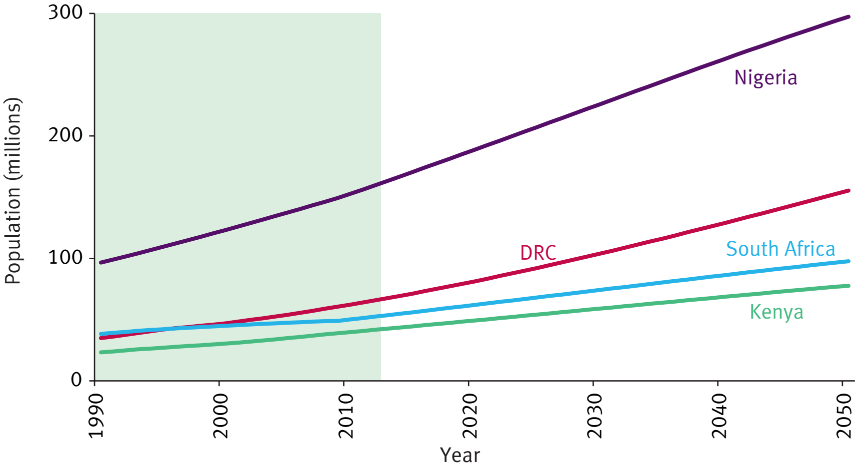


Note: shaded area denotes observed data

Source: UNPD (2013).

Figure 8 shows projections of GDP per capita for sub-Saharan Africa and other regions assuming historical growth rates continue. The GDP per capita in both South Asia and sub-Saharan Africa is well below the GDP per capita in Latin America and East Asia. Despite having similar levels of per capita GDP in 1990, South Asia has recently been growing much faster and now has roughly double the per capita GDP of sub-Saharan Africa. This divergence, if it continues, will lead to a roughly threefold difference in GDP per capita by 2050. There is however considerable heterogeneity in the historical economic growth of countries within sub-Saharan Africa. This difference will lead to increasing divergence across countries in the region if it continues into the future (Fig. 9). For example, South Africa begins in 1990 with somewhat higher per capita GDP than South Asia, but experiences somewhat lower growth rates. Nigeria, Kenya, and the DRC have lower GDP per capita and slower growth rates than South Asia. Per capita GDP will be much higher than it is today in South Africa, Nigeria, and Kenya by 2050 if historical growth rates continue. However, GDP per capita growth in the DRC has been near zero.

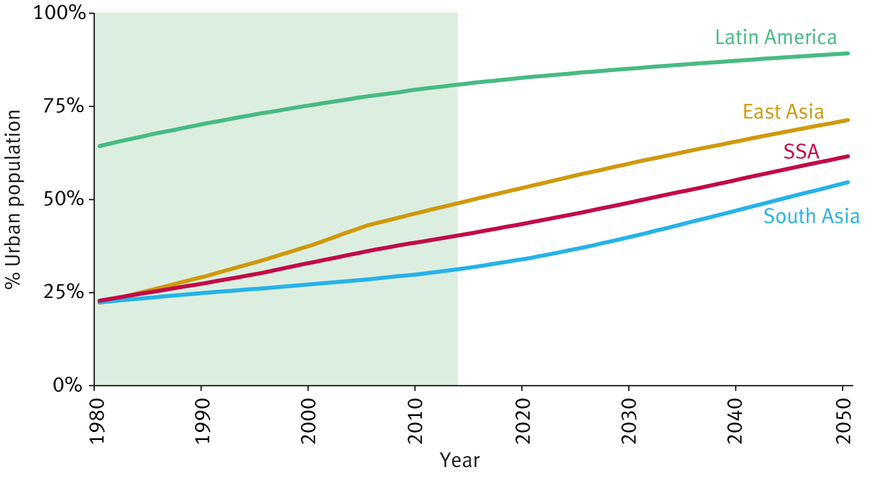
Figure 6. Baseline population projections for Nigeria, Democratic Republic of the Congo (DRC), South Africa, and Kenya



Note: shaded area denotes observed data

Source: UNPD (2013).

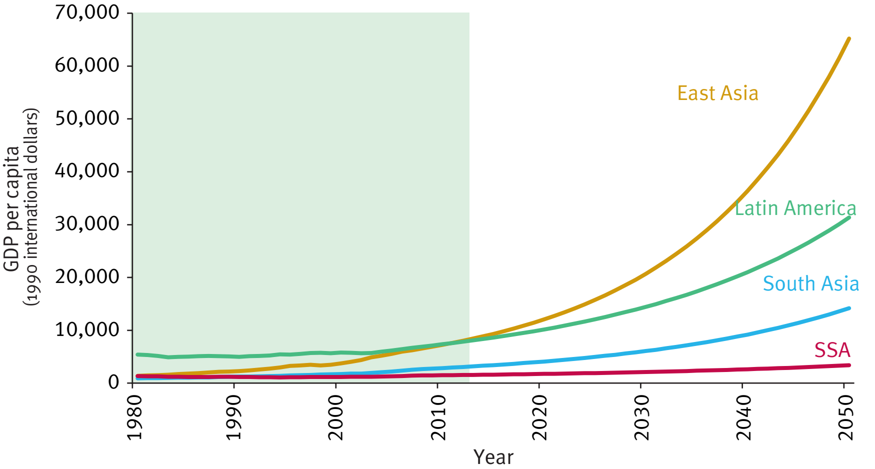
Figure 7. Estimates of the percentage of the population living in urban areas from 1980 to 2050 for four regions



Note: shaded area denotes observed data

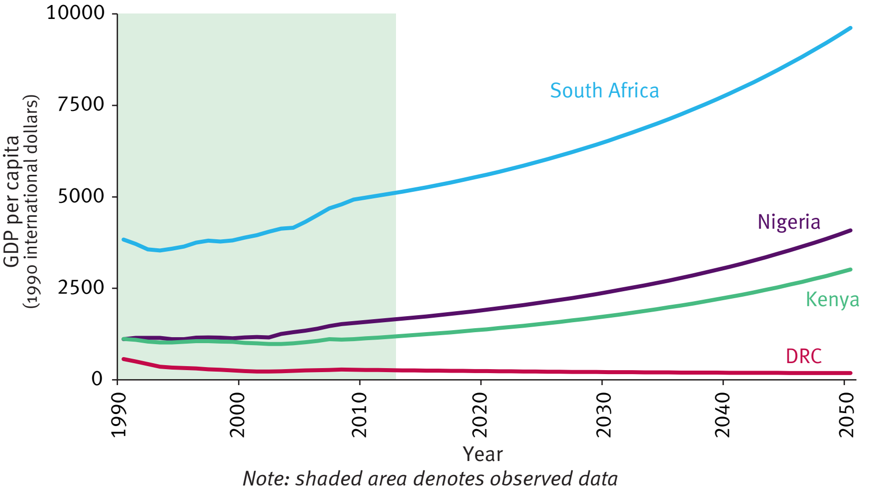
Source: UNPD (2014).

Figure 8. Baseline projections of GDP per capita in four regions



Note: shaded area denotes observed data

Figure 9. Baseline projections of GDP per capita in South Africa, Nigeria, Kenya, and DRC

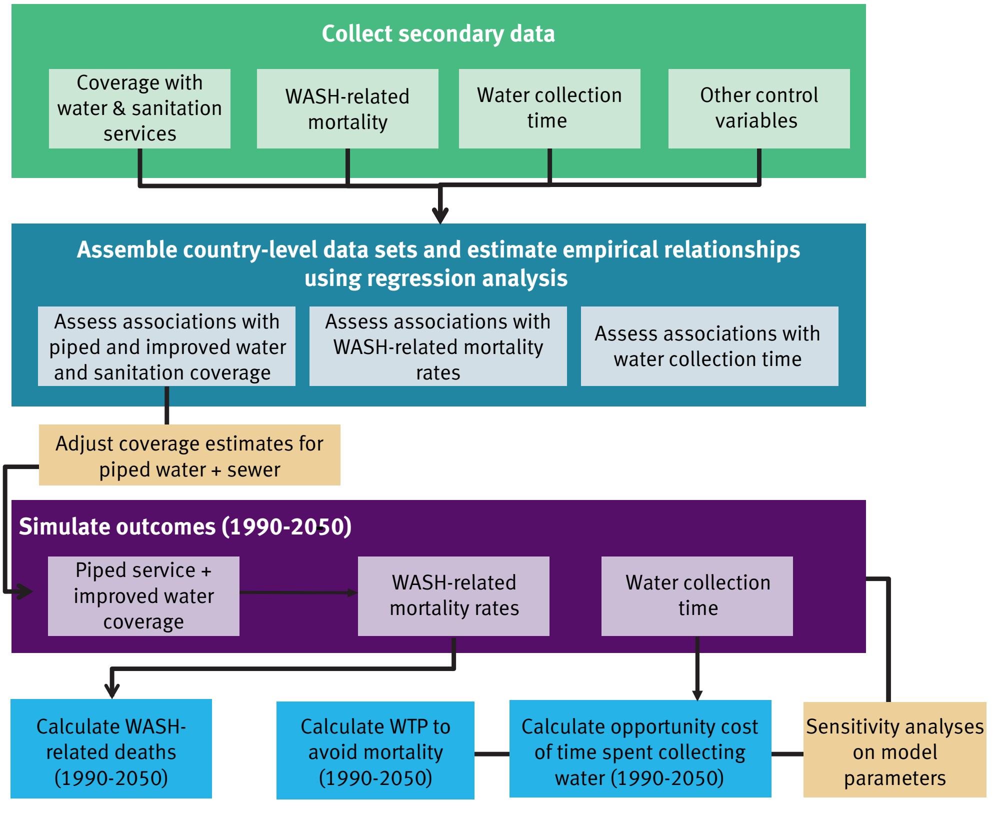


Note: shaded area denotes observed data

4 Modelling strategy and data

In this paper we use the simulation model developed and discussed in Jeuland et al. (2013a) to predict the WASH mortality rate and annual WASH-related deaths from 1990 to 2050. The simulation model consists of three primary steps. In the first step we use regression analysis to estimate: 1) the association between GDP, urbanisation, and access to improved water sources; 2) the association between GDP, access to improved water sources, and WASH-related mortality; and 3) the association between GDP, access to improved water sources, urbanisation, and the time households spend collecting water. In the second step, we combine the parameter estimates obtained in these three regressions with exogenous projections of GDP, population, and urbanisation to forecast access to improved water sources, WASH-related mortality, and time households spend collecting water through 2050 for each country. In the third and final step we estimate the economic losses associated with the health and time-related outcomes we forecast. A schematic of the forecasting model is shown in Fig. 10.

Figure 10. Schematic diagram of the simulation model



Source: Adapted from Jeuland et al. (2013a).

In the first step we estimate the association between GDP and access to improved water sources (Equation 1).

$$Coverage_{it} = \kappa_0 + \kappa_Y \cdot \ln(Y_{i,t-1}) + \kappa_2 \cdot Z_{ij,t} + \delta_{i,t} + \mu_i \qquad \text{(Eq.1)}$$

where $Coverage_{it}$ is access to improved water sources, $Y_{i,t-1}$ is lagged income, $Z_{ij,t}$ is a vector of j country-level control variables (WHO regional dummy variables, linear time trend, year dummy variables, percentage urban population, income inequality, several governance variables, bilateral aid received for WASH, and a set of time–region interaction variables) measured at time t for country i, $\delta_{i,t}$ is a time-varying error term, μ_i is a time-invariant error term, and κ_n are the model coefficients estimated using regression analysis. We estimate this regression equation for both JMP definitions of improved water coverage. (See Jeuland et al. [2013a] for additional details about our estimation strategy and regression results.)

We then estimate the relationship between WASH-related mortality (d_{it}^{WASH}), access to improved water sources (W_{ilt}), and other control variables (Equation 2).

$$d_{it}^{WASH} = \alpha_0 + \alpha_Y \cdot \ln(Y_{it}) + \beta \cdot W_{ilt} + \gamma \cdot X_{ikt} + \varepsilon_i \qquad \text{(Eq.2)}$$

where d_{it}^{WASH} is the WASH-related mortality in country i at time t, Y_{it} is per capita GDP (1990 international dollars), W_{ilt} is a vector of l water coverage variables, and X_{ikt} is a vector of k other control variables (regional dummy variables, percentage urban population, income inequality, fertility, literacy, and several governance variables: democracy-autocracy score (polity), regime durability, and an indicator for coups d'état). We estimate Equation 2 using both piped water on premises and access to an improved water source as control variables. The results of these regressions are also presented in Jeuland et al. (2013a).

Finally, we estimate the relationship between the time households spend collecting water using Equation 3.

$$t_{it}^{collection} = \theta_0 + \theta_Y \cdot \ln(Y_{it}) + \tau \cdot W_{ilt} + \gamma \cdot X_{ikt} + \varepsilon_i \qquad \text{(Eq.3)}$$

where, $t_{it}^{collection}$ is the average one-way water collection time for households in country i at time t, Y_{it} and W_{ilt} are defined as in Equation 2, X_{ikt} is a vector of control variables (per capita GDP, urbanisation, income inequality, regime durability, democracy-autocracy score, and indicator variables for the source of the water collection time data [i.e. MICS, DHS, and WHS]). Regression results are presented in Jeuland et al. (2013b).

The relationships we estimate in Equations 1,2, and 3 should not be interpreted as implying a causal link between GDP per capita, access to improved water sources, and decreased mortality or the time households spend collecting water. However, the associations between these variables are strong, which increases our confidence that these associations can be used for our forecasting purposes (Jeuland et al., 2013a).

To forecast access to improved water sources over the simulation period, we combine the parameter estimates obtained in Equation 1 with exogenous projections of GDP and urbanisation, as shown in Equation 4.

$$Coverage_{it} = Coverage_{it-1} + \kappa_Y \cdot \Delta Y_{it} + \kappa_{urban} \cdot \Delta Urban_{it} \qquad \text{(Eq.4)}$$

where $Coverage_{it}$ is the coverage level in country *i* at time *t*, $Coverage_{it-1}$ is the coverage the previous year, κ_Y is the elasticity of coverage with respect to GDP from Equation 1, ΔY_{it} is the change in GDP from time *t-1* to time *t*, κ_{urban} is the elasticity of coverage with respect to urbanisation from Equation 1, and $\Delta Urban_{it}$ is the change in the percentage of the population living in an urban area from time *t-1* to time *t*. We use Equation 4 to forecast coverage levels for both the JMP's least restrictive definition of improved water as well as piped water on premises using the coverage level specific elasticities estimated from Equation 1.

After forecasting coverage with improved and piped water services, the simulation model then estimates the WASH mortality rate in each country as described in Equation 5.

$$d_{it}^{WASH} = d_{it-1}^{WASH} + \alpha_Y \cdot \Delta Y_{it} + \beta_{imp} \cdot \Delta Improved_{it} + \beta_{piped} \cdot \Delta Piped_{it} \qquad \text{(Eq.5)}$$

Where d_{it}^{WASH} is the WASH mortality rate is defined as in Equation 2; α_Y, β_{imp}, and β_{piped} are the elasticities of WASH mortality with respect to GDP, access to improved water, and access to piped water from Equation 2, respectively; ΔY_{it} is the change in GDP from period *t-1* to *t*; $\Delta Improved_{it}$ is the change in access to improved water; and $\Delta Piped_{it}$ is the change in access to piped water. We then calculate the annual WASH-related deaths in each country by multiplying the projected WASH mortality rate in each period by the projected population for each country during that period.

Equation 6 describes how the simulation model forecasts water collection times.

$$t_{it}^{collection} = t_{it-1}^{collection} + \theta_Y \cdot \Delta Y_{it} + \gamma_{urban} \cdot \Delta Urban_{it} \qquad \text{(Eq.6)}$$

where, $t_{it}^{collection}$ is the average one-way water collection time for households in country *i* at time *t*; ΔY_{it} is the change in GDP from period *t-1* to *t*; $\Delta Urban_{it}$ is the change in the percentage of population that lives in an urban area; and θ_Y and γ_{urban} are parameter estimates from Equation 3.

In addition to forecasting trends in WASH-related mortality and water collection times, we estimate the magnitude of economic losses associated with the lack of access to water and sanitation services over the simulation horizon. Conceptually, the economic benefits of access to water services for households consist of health benefits, time-savings, and aesthetic benefits.[14] Owing to a paucity of country-level data on households' willingness to pay for aesthetic benefits associated with improved water services, our estimates of economic losses include only WASH-related mortality, morbidity, and water collection time (Equation 7).

$$Losses_{it}^{\mathrm{WSH}} = H_{it} + T_{it} \qquad \text{(Eq.7)}$$

where $Losses_{it}^{\mathrm{WSH}}$ is the total WASH-related economic losses in country *i* in period *t* and H_{it} are T_{it} are the health- and time-related losses, respectively, associated with not having access to adequate water and sanitation services.

We estimate the economic losses associated with WASH-related mortality using the economic concept of the value of statistical life (VSL).[15] Specifically, we calculate the economic losses associated with WASH-related mortality by multiplying the number of projected WASH-related deaths each year in each country by the forecast VSL for that country (Equation 8). Owing to

[14] We note that framing the economic consequences associated with improving access to water services as 'reduced economic losses' instead of 'economic gains' reinforces a donor perspective in considering global challenges (Whittington, 2010). See Jeuland et al. (2013b) for a more detailed discussion of the problem of framing.

[15] See Jeuland et al. (2013b, Annex 10.1) for a detailed description of how we forecast the VSL in our models.

a lack of country-level data on disease incidence rates, we estimate the economic losses associated with WASH-related morbidity as a fraction of the WASH-related mortality losses. Following Whittington et al. (2009a) we assume that morbidity losses are 25 percent of mortality losses and vary this from 10 percent to 40 percent in our sensitivity analysis (Equation 8).

$$H_{it} = Pop_{it} \cdot d_{it}^{WSH} \cdot VSL_{it} \cdot (1 + f_{morb}) \qquad \text{(Eq.8)}$$

where H_{it} is the WASH-related mortality and morbidity losses in country *i* in period *t*; Pop_{it} is the population in country *i* in period *t*; d_{it}^{WSH} is the WASH-related death rate in country *i* in period *t* from Equation 5; VSL_{it} is average value of statistical life in country *i* in period *t*; and f_{morb} is the fraction of morbidity burden.

We estimate the economic losses associated with the time households spend collecting water by estimating the total amount of time households spend collecting water each year and then multiplying this projection by the opportunity cost of time for each country (Equation 9). Following Jeuland et al. (2013b), we assume that the opportunity cost of time is a fraction of the average per capita GDP going to the bottom 80 percent of the income distribution.

$$T_{it} = \left(\frac{Pop_{it}}{hhsize_{it}}\right) \cdot 2^{trips} \cdot t_{it}^{collection} \cdot v_{it}^{t} \qquad \text{(Eq.9)}$$

where T_{it} are the WASH-related time losses in country *i* in period *t*; Pop_{it} is the population of country *i* in period *t*; $hhsize_{it}$ is the average household size in country *i* in period *t*; $t_{it}^{collection}$ is the average one-way water collection time from Equation 6; and v_{it}^{t} is the opportunity cost of time. Thus, both the economic value of time-savings and the VSL increase as GDP per capita increases over the forecast period.

4.1 Base case scenario

In our base case we forecast the WASH mortality rate and annual WASH-related deaths for each country over the simulation period using the JMP's least restrictive definition of access to improved water sources as the measure of coverage (Equation 5).[16] In the base case scenario we use the parameter estimates obtained in Equations 1 and 2 and assume that countries' GDP increase at the same average rate as they did over the historical period 1950–2008.

We then use Monte Carlo analysis to test the sensitivity of the results to our assumptions about GDP growth as well as the strength of the association between GDP, coverage, urbanisation, and WASH-related mortality. In particular, in the Monte Carlo simulation we draw the average annual growth rate for each country from a normal distribution with a mean of 3.7 percent and a standard deviation of 3 percent. This reflects the distribution of GDP growth rates in sub-Saharan Africa from 1990 to 2008, a period over which GDP growth among countries in the region varied considerably. We also vary the strength of the association between GDP, coverage, urbanisation, and WASH-related mortality using the 95 percent confidence intervals of the parameter estimates obtained from Equations 1 and 2. We draw 1,000 realisations of the model parameters to obtain a distribution of outcomes from the simulation model. (Table 1 lists the parameters used in the Monte Carlo simulations, their upper and lower bounds, and the type of distribution assumed.)

[16] We use JMP's least restrictive definition of improved water in our base case because the projections derived using this definition of improved water are more consistent with the trends in WASH mortality we observe in the recent past.

Table 1. Summary of parameters, parameter ranges, and distributional assumptions used in the Monte Carlo simulations

Simulation parameter	Base case	Lower bound	Upper bound	Distribution
GDP	Historical growth*	N/A	N/A	Normal dist. N(3.6, 3.00)
Coverage				
Piped water GDP elasticity	9.5	4.5	14.5	Uniform dist.
Piped water % Urban elasticity	0.35	0.1	0.6	Uniform dist.
Improved water GDP elasticity	4.5	0	9	Uniform dist.
Improved water % Urban elasticity	0.3	0.1	0.5	Uniform dist.
WASH mortality				
GDP elasticity	-0.2	-0.1	-0.3	Uniform dist.
Piped water elasticity	-0.02	-0.01	-0.03	Uniform dist.
Improved water elasticity	-0.0275	-0.01	-0.045	Uniform dist.
Time to water				
Time to water GDP elasticity	-1.2	-0.3	-2.1	Uniform dist.
Time to water % urban elasticity	-0.06	-0.02	-0.1	Uniform dist.
Average household size	5	4	6	Uniform dist.
Number of trips per day	1.5	1	2	Uniform dist.
Economic losses				
Health losses				
VSL	(*see Jeuland et al., 2013b: Annex 10.1*)			
Morbidity as % of mortality (f_{morb})	0.25	0.4	0.1	Uniform dist.
Time losses				
Hours per work week	40	30	50	Uniform dist.
Shadow value of labour (fraction of per capita GDP**)	0.25	0.1	0.5	Uniform dist.

* Average annual growth rate from 1950 to 2008.
** See Jeuland et al. (2013b) for details.

4.2 Data

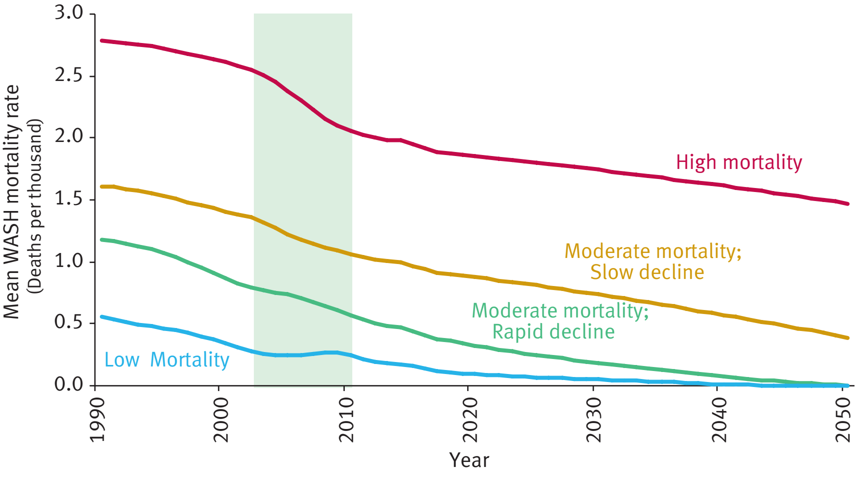
The regression analyses (Equations 1 and 2) use country-level data from different global data sets (see Jeuland et al., 2013a). WASH-related mortality (i.e. the ratio of total number of deaths due to WASH to total number of deaths) was calculated for 2002 and 2008 using the methodology from the WHO's Environmental Burden of Disease (EBD) project. Data for 2004 WASH-related mortality were taken directly from the EBD. Data for coverage with improved sources and for piped water services from 1990 to 2015 were obtained from the JMP.[17] Adult literacy and fertility rates were obtained from the United Nations, while governance variables were obtained from the Center for Systemic Peace's Integrated Network for Societal Conflict Research. These governance variables included measures of the extent of democracy and autocracy, years since regime change, and an indicator for a successful coup in the last five years. Income inequality was measured as the percentage of national GDP for the lowest 80 percent of the income distribution, which was obtained from the World Bank (World Bank, 2013). We obtained the country-level data for water collection time from the Demographic and Health Survey (DHS), the Multiple Indicator Cluster Survey (MICS), and the World Health Surveys (WHS) of the WHO. For the simulations, we use urbanisation and population projections from the United Nations Population Division.

[17] Jeuland et al. (2013a) use JMP data from 1990 to 2010. We incorporate the latest JMP estimates for 2015 in the simulation model for this analysis. Appendix 3 summarises how the forecasts for access to improved water and piped water from Jeuland et al. (2013a) compare with the most recent JMP data for all countries in our dataset.

5 Results

Figure 11 shows the base case projections of the average WASH-related mortality rate for the four groups of sub-Saharan Africa countries shown in Fig. 1. Countries in the first group currently have high WASH-related mortality rates (approximately 2 deaths per 1,000 annually), and our projections indicate that these rates will not decline much (only 25 percent) by 2050. In the base case our projections show that the WASH mortality rate will be approximately 1.5 deaths per thousand annually in 2050. This is substantially higher than the WASH mortality rate in the other three groups of sub-Saharan Africa countries today. Countries in this first group include Angola, Burkina Faso, Burundi, Central African Republic, Chad, DRC, Ethiopia, Guinea Bissau, Liberia, Mali, Niger, Sierra Leone, and Somalia.

Figure 11. Base case projections of WASH mortality rates for four groups of sub-Saharan Africa countries (1990–2050)



Note: shaded area denotes observed data

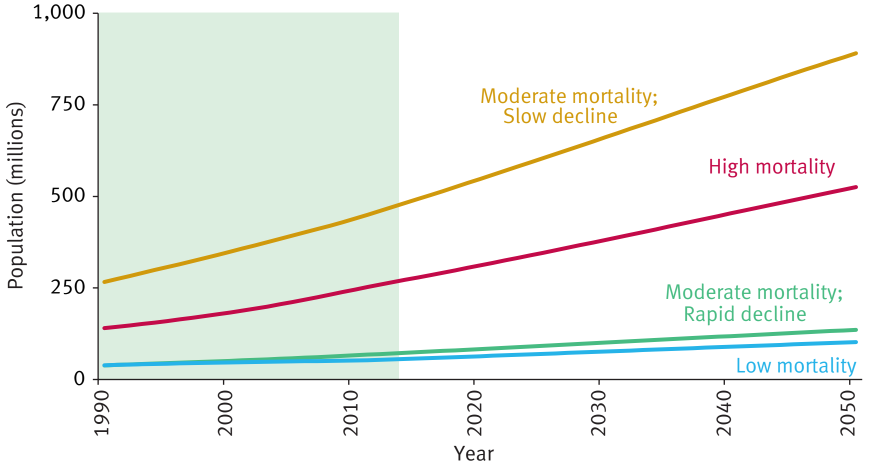
Countries in the second group currently have moderate WASH mortality rates (>1 death per thousand), and these decline steadily (by over 50 percent) over the simulation period to approximately 0.5 deaths per 1,000. Many countries in sub-Saharan Africa fall into this second group, including Benin, Cameroon, Comoros, Congo, Cote d'Ivoire, Ghana, Guinea, Madagascar, Malawi, Mauritania, Mozambique, Nigeria, Rwanda, Sudan, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

Countries in the third group start with moderate mortality rates (0.5 deaths per thousand), just above the WASH mortality in South Asia today. These rates decline significantly over the simulation period, reaching negligible levels by 2050. Countries in this third group include Botswana, Equatorial Guinea, Eritrea, Gambia, Kenya, Lesotho, Namibia, Senegal, Swaziland, and Zimbabwe.

Countries in the fourth group start with relatively low WASH-related mortality (under 0.5 deaths per thousand). WASH-related mortality in this group of countries increases between 2002 and 2008 and then forecast to decline to negligible levels by 2035. With the exception of South Africa, these countries are mostly small (Cape Verde, Gabon, Mauritius, Seychelles, and South Africa).[18]

Figure 12 shows forecasts of the total population (from the United Nations Population Division) of each of the four groups of countries to 2050. Throughout the period, the population of countries in Group 2 is larger than the population of all three other groups combined. By 2050, the combined population of Group 1 (high mortality) and Group 2 (moderate mortality, slow decline) is over 1 billion people.

Figure 12. Baseline population forecasts for four groups of sub-Saharan Africa countries

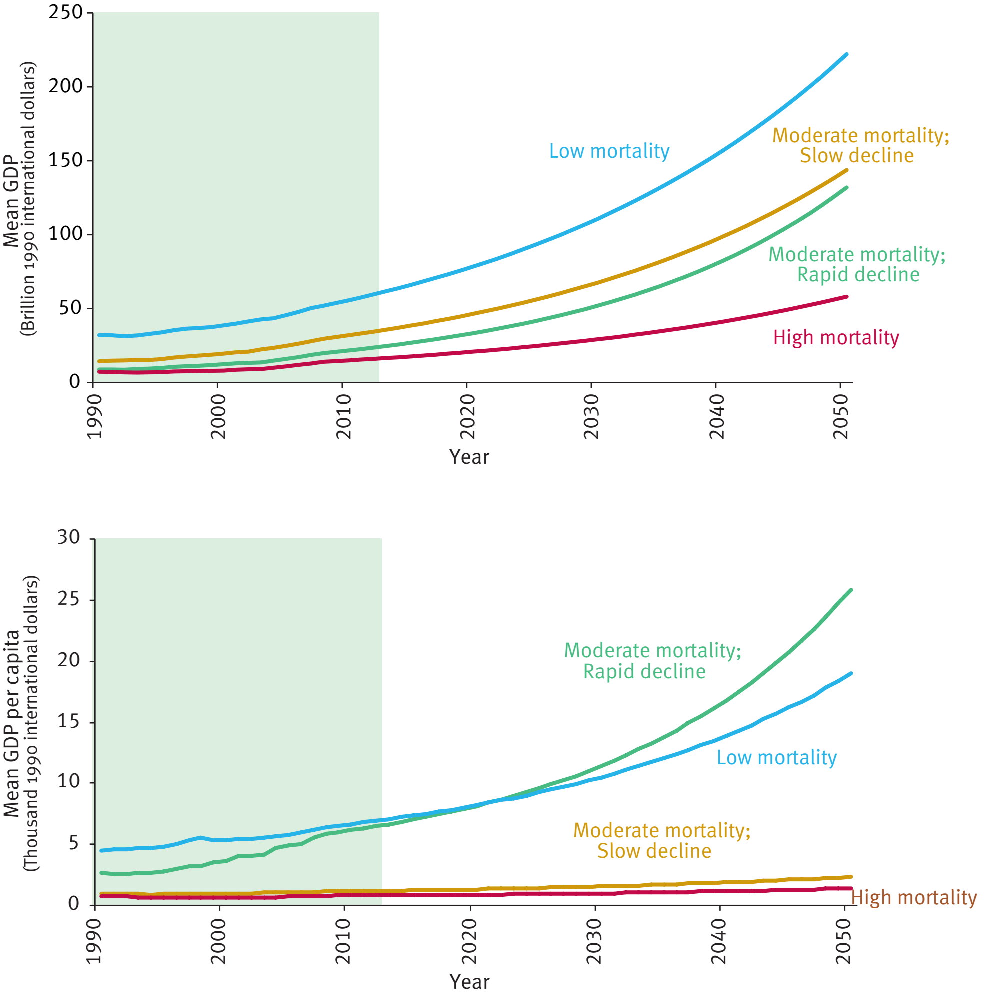


Note: shaded area denotes observed data

Figure 13 shows the GDP forecasts based on maintaining historical long-term growth rates for each of the four groups of countries to 2050. GDP per capita in Groups 1 and 2 is lower than in Groups 3 and 4 in 1990. Over the period of the forecast, these groups fall further and further behind Groups 3 and 4 in relative terms. For Groups 1 and 2 the high population forecasts, low initial GDP per capita, and assumed modest economic growth rates combine to hold back improvements in improved water coverage and WASH-related mortality rates.

18 As we discuss further below, the increase in mortality rates in this group during the historical period for which we have data is driven by the increased mortality estimated for South Africa by the WHO.

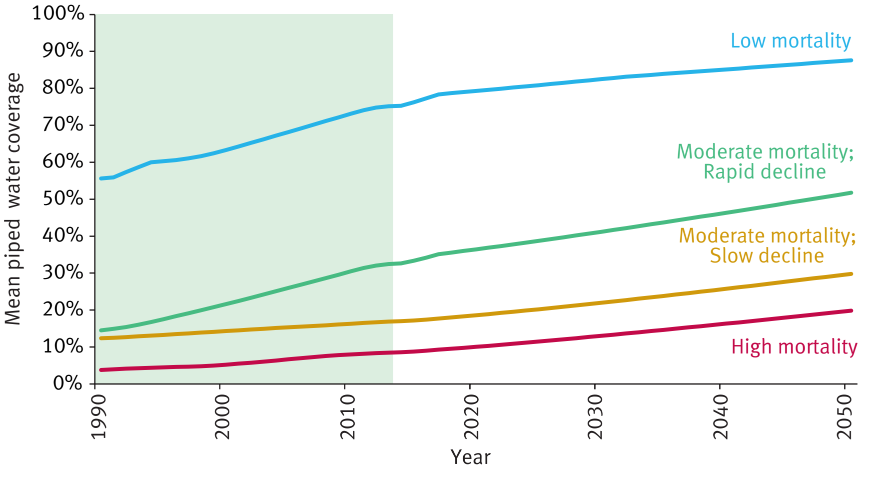
Figure 13. Baseline GDP forecasts for the four groups of sub-Saharan Africa countries (top panel: GDP; bottom panel: GDP per capita)



Note: shaded area denotes observed data

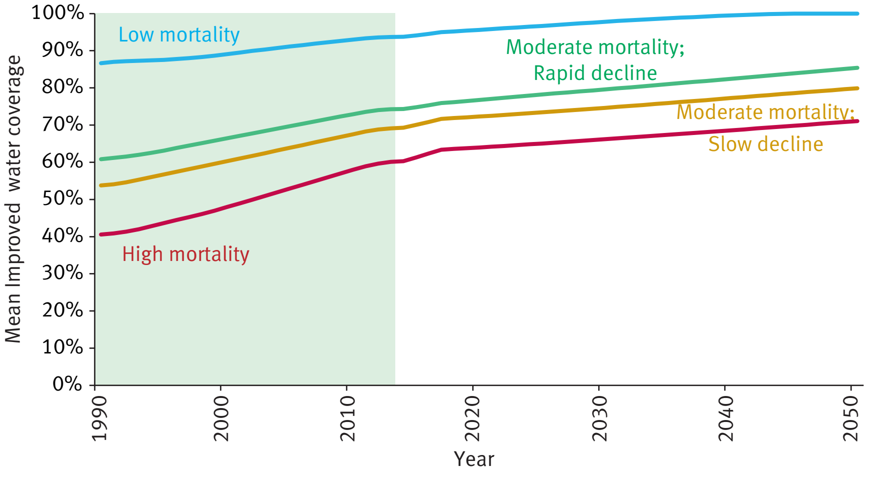
Figures 14 and 15 show the forecasts of piped and improved water coverage by country group to 2050, respectively. Group 4 exhibits much higher levels of both improved water coverage and piped water coverage over the simulation period than the other three groups. Group 2 and Group 3 exhibit similar levels of coverage with improved water sources. However, Group 3 is forecast to have much higher levels of piped water coverage throughout the simulation period (Fig. 14). Despite this, we project that less than 50 percent of the population in Group 3 countries will have access to piped water sources in 2050. According to the latest JMP data, approximately half the population in Group 1 has access to an improved water source and only

Figure 14. Forecast for piped water coverage for the four groups of sub-Saharan Africa countries



Note: shaded area denotes observed data

Figure 15. Forecast for improved water coverage for the four groups of sub-Saharan Africa countries



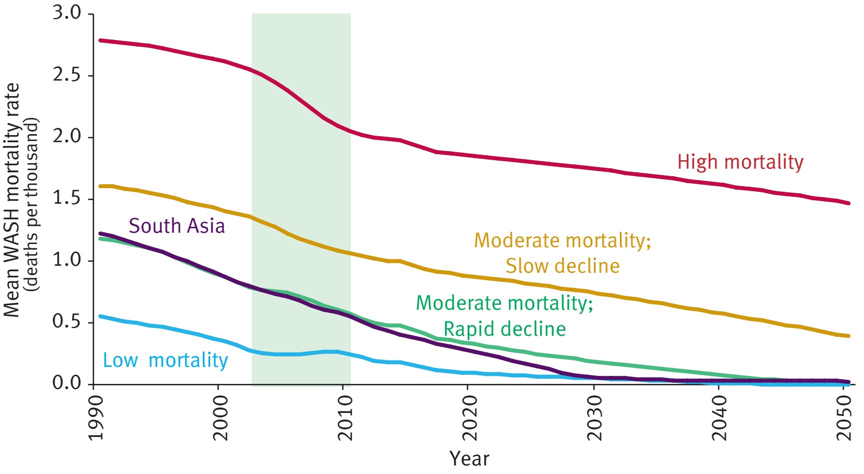
Note: shaded area denotes observed data

10 percent of the population in Group 1 has access to a piped water source today. Over the simulation period, we project that coverage levels for both improved and piped water will remain low for Group 1 countries.

5.1 WASH-related mortality forecasts

Figure 16 shows our forecasts for the WASH-related mortality rate in the four sub-Saharan Africa country groups compared with South Asia. The mortality rate for all four groups is trending down, but the baseline mortality rates differ markedly across the four groups. Our forecasts indicate that Group 4 countries, which have low WASH mortality rates today, will see the WASH mortality rate decline to negligible levels around 2040, approximately the same WASH mortality rate trajectory as South Asia. The results of our Monte Carlo analysis (Fig. 17) suggest that the 50 percent confidence interval for the WASH mortality rate in Group 4 countries spans from 'near zero' levels as early as 2030 on the optimistic side to a more pessimistic projection of 0.1 deaths per thousand in 2050.[19]

Figure 16. Trends in WASH mortality rates for the four sub-Saharan Africa country groups and South Asia



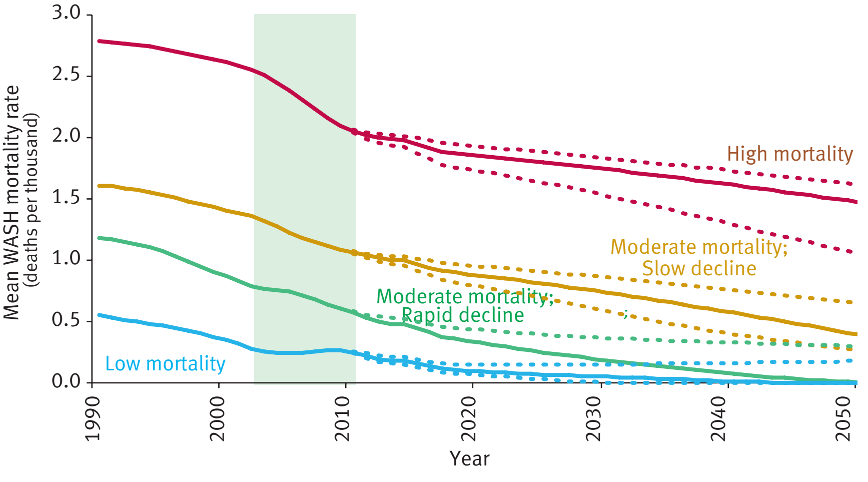
Note: shaded area denotes observed data

We project that the WASH mortality rate will also fall to negligible levels over the simulation period in Group 3 countries, but approximately 10 years after South Asia and Group 4 countries. However, the Monte Carlo analysis suggests that the WASH mortality rate in Group 3 countries could remain as high as 0.2 deaths per thousand in 2050.

The WASH mortality rate in Groups 1 and 2 is projected to be much higher than the WASH mortality rate in South Asia over the entire simulation period. Our Monte Carlo analysis suggests that even on the optimistic side of the interquartile range (spanning the 25th to 75th percentile of the distribution), the WASH mortality rate in Group 1 still will be well above 1 death per thousand by the end of the simulation period (Fig. 17). The WASH mortality rate in Group 2 countries is not projected to reach the current WASH mortality rate in South Asia (approximately 0.5 deaths per thousand) until 2045. The Monte Carlo results suggest the WASH mortality rate could remain as high as 0.6 deaths per thousand at the end of the simulation period.

[19] The 50 percent confidence interval includes outcomes that are above the 25th percentile and below the 75th percentile of the distribution of outcomes from the Monte Carlo simulation.

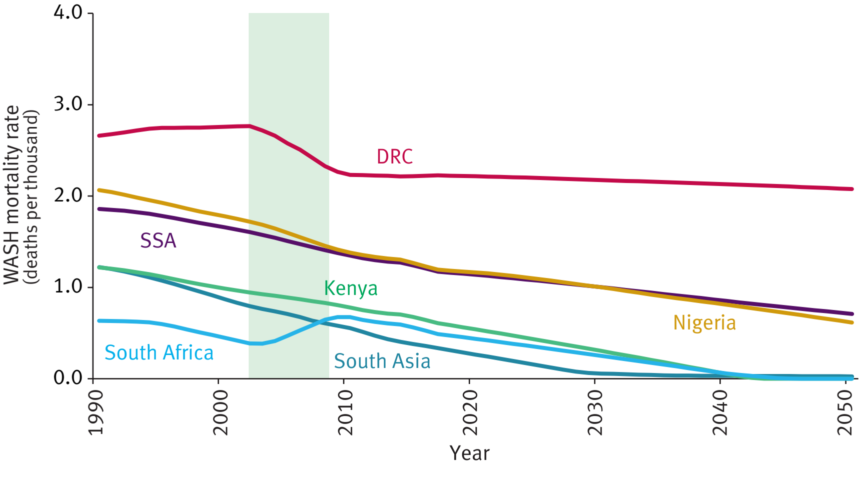
Figure 17. WASH mortality rates for the four groups of sub-Saharan Africa countries; base case projections (solid lines) with the interquartile range from the Monte Carlo simulation (dotted lines)



Note: shaded area denotes observed data

Figure 18 shows our forecasts for WASH-related mortality rates for four large countries in sub-Saharan Africa (South Africa, DRC, Nigeria, and Kenya), one from each of the four country groups, compared with our forecast for South Asia. These country-specific mortality rate forecasts tell a more nuanced story than the forecasts for the country groups and highlight potential limitations of the model and the data we use. For example, the WASH mortality rate for

Figure 18. Forecasts of WASH-related mortality rates for South Africa, DRC, Nigeria, and Kenya



Note: shaded area denotes observed data

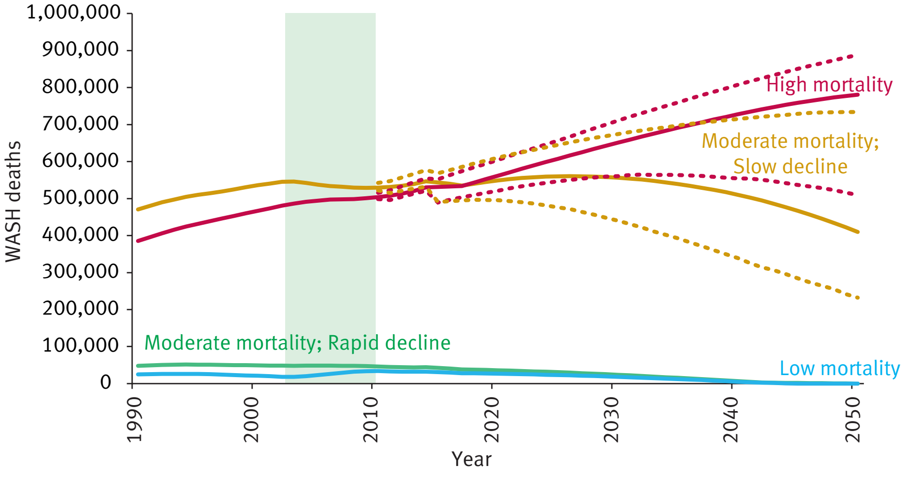
the DRC shows a sharp drop from 2002 to 2008 even though GDP growth over this period was negative, which is clearly not consistent with the average relationships between these variables. Given the instability in the DRC over the past decade, it seems unlikely that the WASH mortality rate decreased so rapidly in this six-year period. Thus, the drop we observe in the DRC may be due to poor data quality in 2002.

Similarly, the WASH mortality rate in South Africa shows a marked increase from 2002 to 2008 even as economic growth was positive; we then forecast a steady decline in the WASH mortality rate over the simulation period. We project that Kenya and South Africa will eliminate WASH-related deaths by approximately 2045.

5.2 Forecasts of WASH-related deaths

Figure 19 presents our forecasts of the total annual WASH-related deaths by country group. As shown, total annual deaths in Group 1 are projected to rise continuously over the period. Only on the optimistic side of the interquartile range of our Monte Carlo simulations do WASH-related deaths in Group 1 begin to decline by 2050. In the base case our simulations indicate that the total number of WASH-related deaths in Group 2 countries will peak around 2025 and then decline over the remainder of the simulation period. Total annual deaths in Group 3 and 4 countries are low and decline continuously over the forecast period.

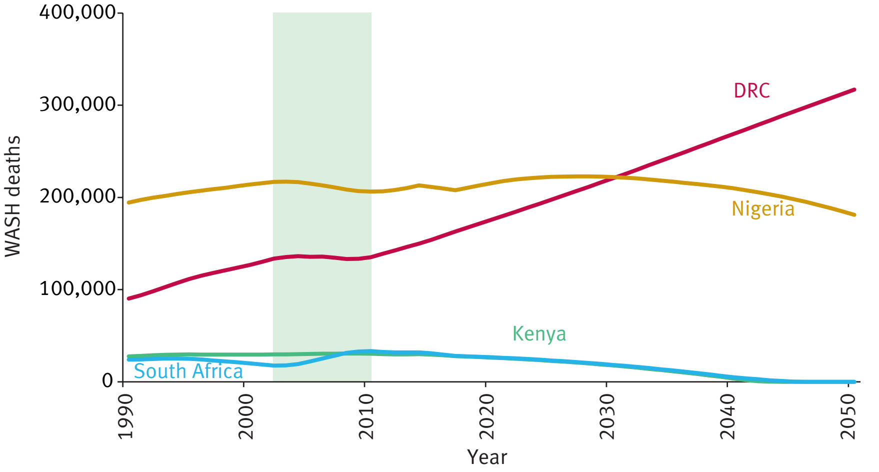
Figure 19. Forecasts of WASH-related deaths for the four groups of sub-Saharan Africa countries; base case projections (solid lines) with the interquartile range from the Monte Carlo simulation (dotted lines)



Note: Shaded area denotes observed data. Confidence intervals not shown for low and moderate rapid decline groups because of scale

Figure 20 presents our base case forecasts of the total annual WASH-related deaths in the same four large countries shown previously (South Africa, Kenya, Nigeria, and the DRC). Annual WASH-related deaths in the DRC are projected to increase throughout the simulation period. Annual WASH-related deaths in Nigeria first rise and then fall, but even by the end of the period the absolute number of deaths remains large. In South Africa and Kenya the total annual deaths declines continuously from the start of the forecast period and is negligible by 2045.

Figure 20. Forecasts of WASH-related deaths for South Africa, DRC, Nigeria, and Kenya



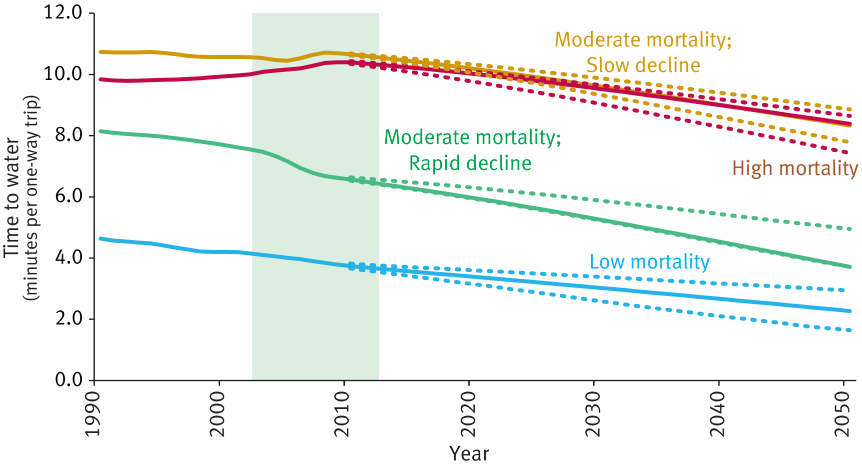
Note: shaded area denotes observed data

5.3 Forecasts of time spent collecting water outside the home

Figure 21 shows our forecasts of the average time households spend collecting water in the four country groups. Water collection times are approximately the same in Group 1 and Group 2 countries. While we project that countries in Group 3 and 4 will eliminate WASH mortality by 2050, our forecasts suggest that average water collection times will remain significant in these countries, even on the optimistic side of the interquartile range from our Monte Carlo simulations. This reflects the fact that Group 4 countries are not forecast to achieve universal coverage with piped water by 2050 and that piped water coverage in Group 3 countries remains below 50 percent throughout the simulation period.

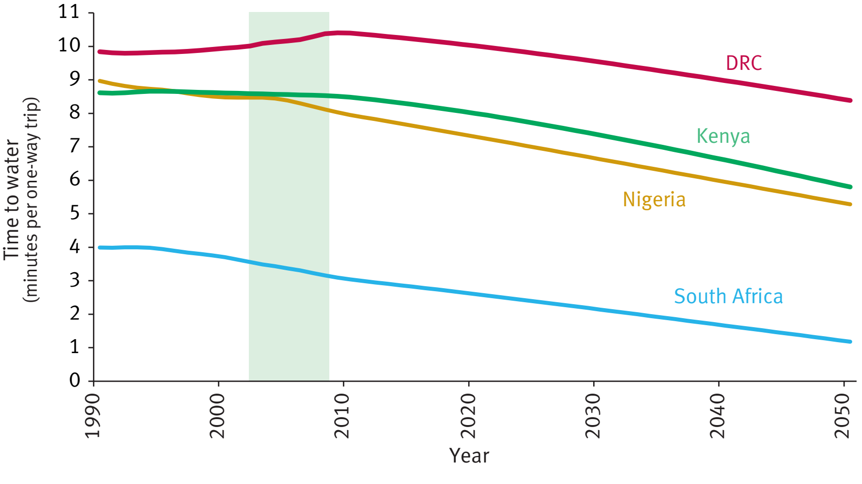
Figure 22 shows our forecasts of water collection times in four large countries (South Africa, Kenya, Nigeria, and the DRC). As above, country-specific trends tell a more nuanced story than the trends among country groups. Despite the fact that the average water collection times are higher in Group 2 countries than in Group 1 countries, the water collection time in the DRC (a Group 1 country) is substantially higher than in Nigeria (a Group 2 country). Indeed, the water collection times in Nigeria are lower than the water collection times in Kenya (a Group 3 country) throughout the simulation period. This is because countries start at different points and collection time reflects population density, water availability, and other factors for which we cannot control.

Figure 21. Forecasts of water collection time in four groups of sub-Saharan Africa countries; base case projections (solid lines) with the interquartile range from the Monte Carlo simulation (dotted lines)



Note: shaded area denotes observed data

Figure 22. Forecasts of the average water collection time in South Africa, DRC, Nigeria, and Kenya

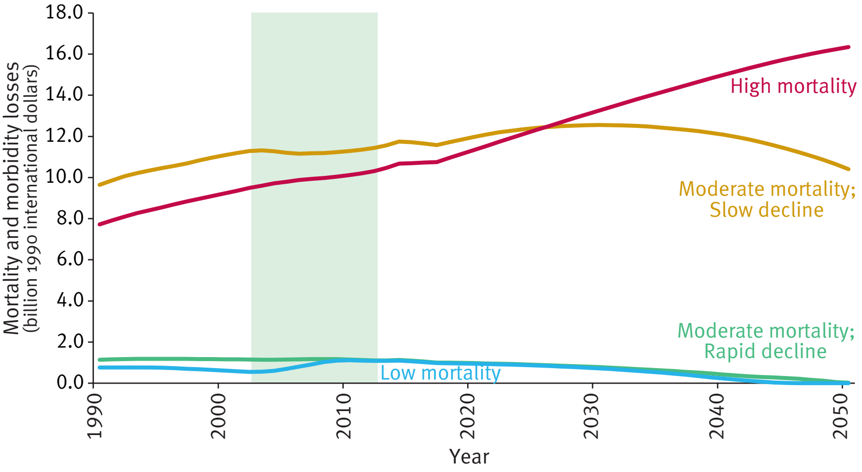


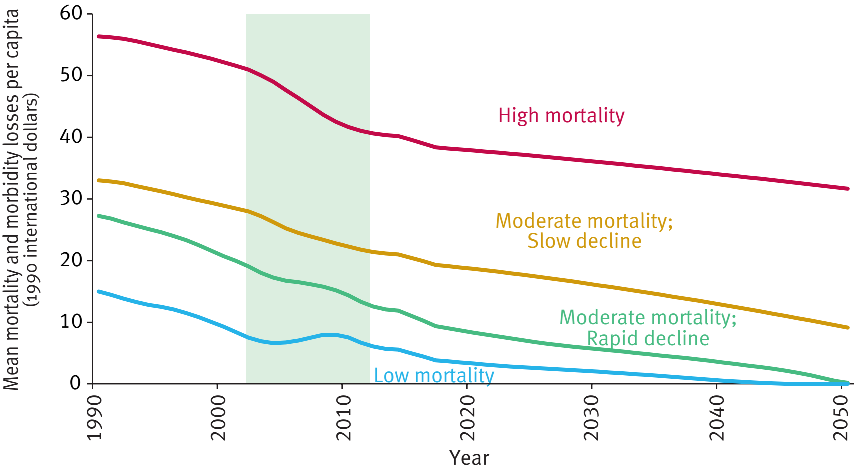
Note: shaded area denotes observed data

5.4 Forecasts of economic losses

We next examine the economic consequences of the trends forecast above. Given the uncertainty in our projections, we focus on the relative dynamics of the health- and time-related losses among countries rather than the absolute magnitude of the economic losses.[20] Figure 23 presents our forecasts of economic losses associated with WASH mortality and morbidity. Group 3 and 4 countries currently experience low levels of health-related losses and, consistent with our forecasts of WASH-related deaths, we forecast that these countries will eliminate health-related economic losses associated with inadequate access to water services by 2050.

Figure 23. Forecasts of the health-related WASH losses in four groups of sub-Saharan Africa countries (top: total health losses; bottom: average per capita health losses)





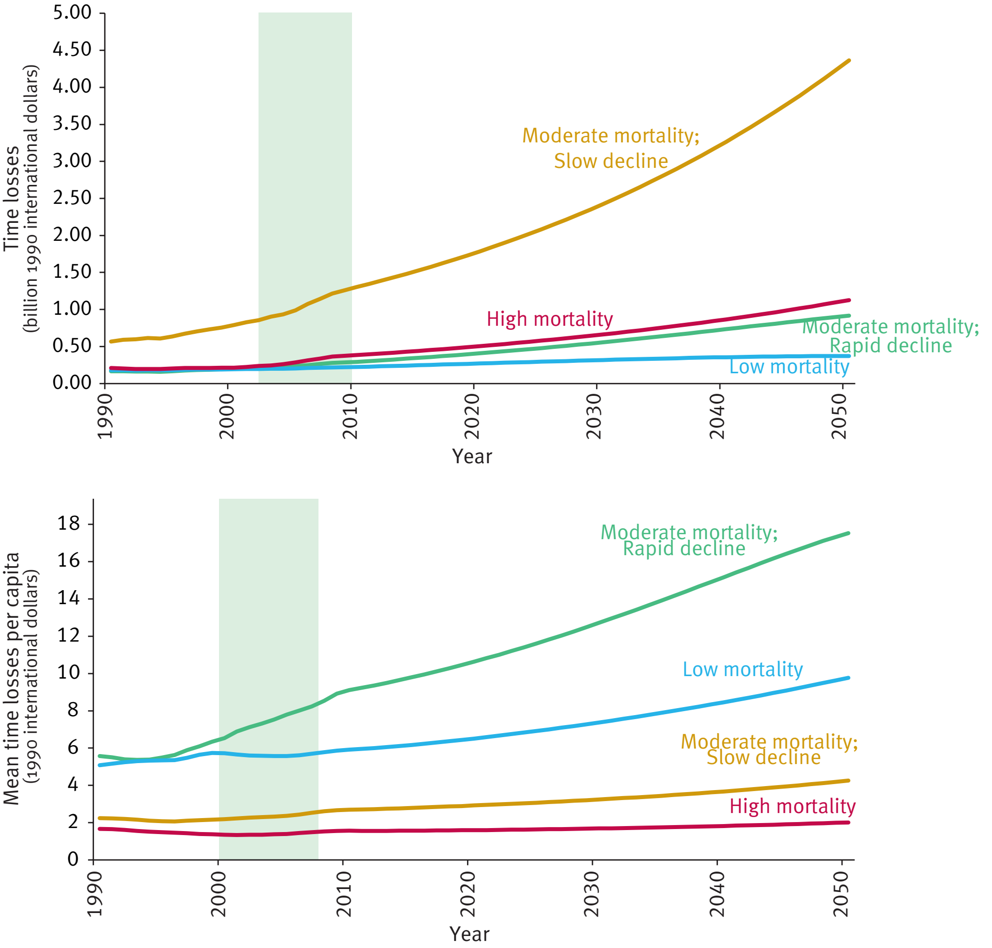
Note: shaded area denotes observed data

[20] For the sake of clarity, we do not show the results of the Monte Carlo simulations for the economic losses results. These are available upon request.

Our forecasts suggest that the economic losses associated with WASH-related mortality and morbidity in Group 2 countries will peak in 2030, five years after the peak in WASH-related deaths in this group of countries. This reflects the fact that per capita incomes continue to rise in these countries, increasing the economic value of mortality risk reduction, even as the absolute number of WASH-related deaths and cases of illness decline. The losses associated with WASH mortality and morbidity in Group 1 countries are currently lower than the losses in Group 2 countries, but we forecast that the total economic losses will continue to rise in Group 1 countries over the simulation period, surpassing the losses in Group 2 countries around 2025. Although we project the total health-related losses in Group 2 countries to rise over the simulation period, we forecast the average per capita health-related losses in these countries to decrease.

Figure 24 shows our forecasts of the economic losses associated with the time households spend collecting water. Despite the fact that Group 3 and Group 4 countries are projected to

Figure 24. Forecasts of the time-related WASH losses in the four groups of sub-Saharan Africa countries (top: total time losses; bottom: average per capita time losses)



Note: shaded area denotes observed data

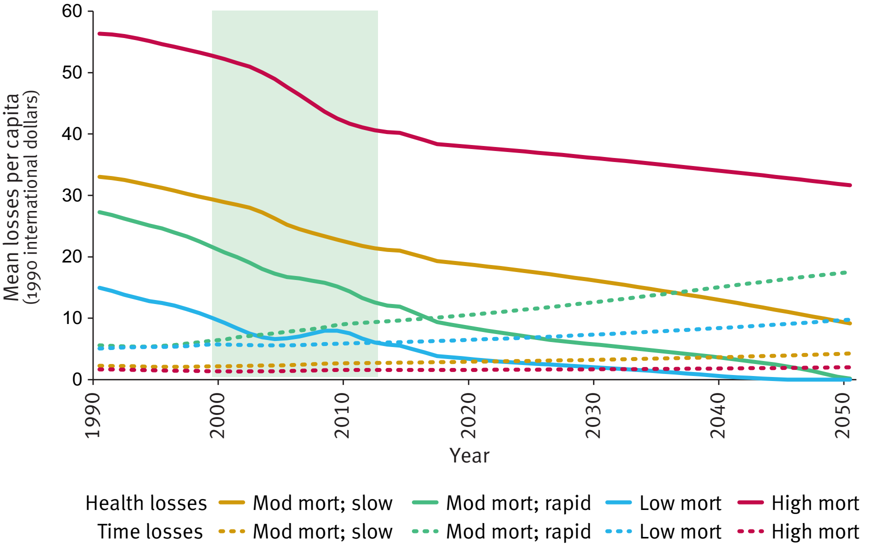
eliminate health-related losses by 2050, our forecasts suggest that the economic losses associated with water collection time in these countries will rise over the simulation period. This reflects the fact that average water collection times in these countries are forecast to remain positive throughout the simulation period and that the opportunity cost of time increases in these countries as incomes rise.

Time-related losses in Group 1 increase at a similar rate as the time losses in Group 3 countries, but are slightly higher throughout the simulation period. The economic losses associated with the time households spend collecting water are highest in Group 2 countries, which are forecast to have high average collection times (Fig. 21) and substantial population growth (Fig. 12).

Forecasts of average per capita time-related losses tell a more nuanced story (Fig. 24, bottom panel). Per capita time losses are lowest in Group 1 countries despite the fact that they exhibit high average water collection times. This reflects both the low opportunity cost of time in these countries as well as the relative size of their populations. Similarly, despite the fact that the total time losses in Group 2 countries increase substantially over the simulation period, average per capita time losses among countries in this group are forecast to remain relatively stable throughout the simulation period. Per capita time losses are the highest in Group 3 countries, which are projected to have modest population growth over the simulation period and substantial increases in per capita GDP (Fig. 13).

Figure 25 compares the average per capita time- and health-related losses. Per capita health losses are currently much larger than per capita time losses in Group 1 and 2 countries, and our forecasts suggest that health losses will continue to be larger than time losses over the simulation period. This is not surprising given the substantial WASH mortality burden we forecast in these countries over the simulation period. In Group 3 and 4 countries we forecast

Figure 25. Forecasts of per capita health and time-related WASH losses in the four groups of sub-Saharan Africa countries

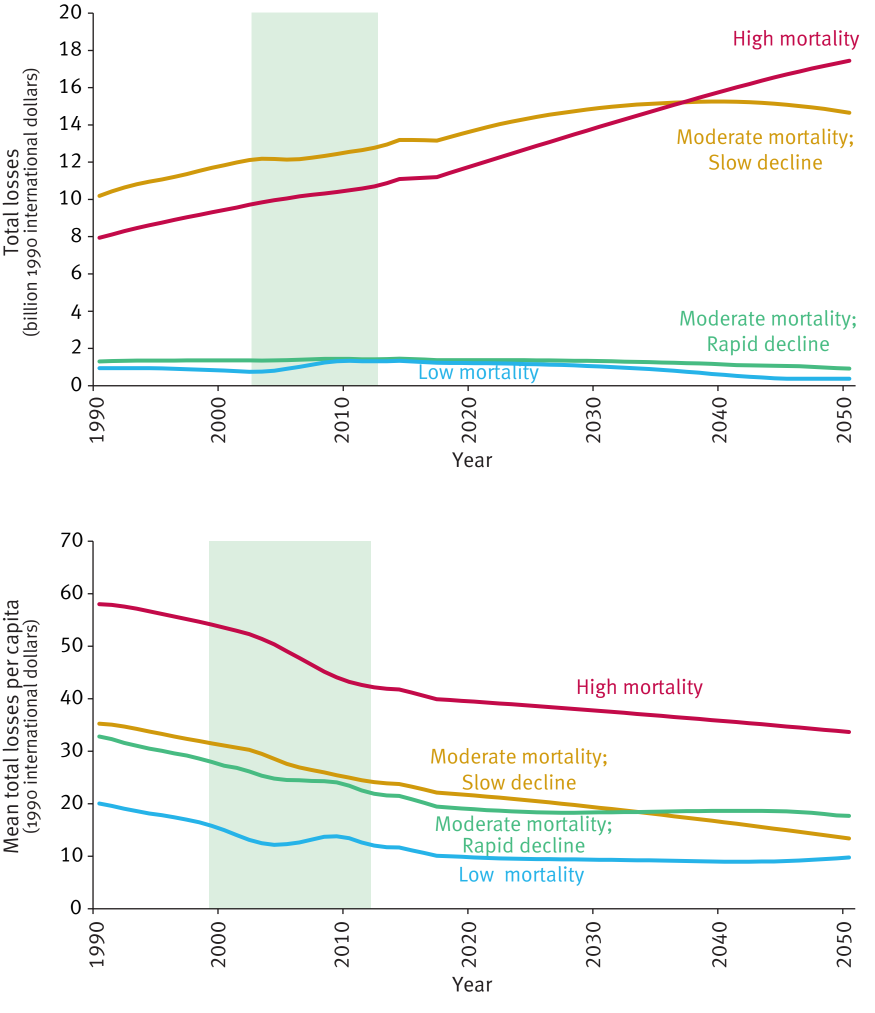


Note: shaded area denotes observed data

a different trend. In Group 4 countries, per capita time losses recently surpassed health losses as the primary driver of economic losses associated with inadequate access to water. Our forecasts suggest that per capita time losses will also soon be larger than per capita health losses in Group 3 countries.

The relative trends we observe in the health- and time-related economic losses associated with inadequate access to improved water services are reflected in our forecasts of total economic losses (Fig. 26). Driven by large health-related losses, the total losses in Group 1 countries are forecast to increase over the simulation period, surpassing the total economic losses in Group 2

Figure 26. Forecasts of the total WASH-related losses in the four groups of sub-Saharan Africa countries (top: total losses; bottom: average per capita losses)



Note: shaded area denotes observed data

countries by approximately 2035. In our base case, the total losses in Group 2 countries are forecast to peak in 2040, ten years after health-related losses begin to decline in this group of countries. Total losses in Groups 3 and 4 are forecast to remain low, but persist throughout the simulation period despite the fact that these countries largely eliminate WASH-related mortality by 2050. Economic losses in these countries persist because of the lack of universal coverage with piped water services and the increasing opportunity cost of time spent collecting water from outside the home.

6 Discussion and conclusions

The findings in Jeuland et al. (2013a) suggested that over the next four decades sub-Saharan Africa will continue to lag behind other regions in expanding access to improved water sources, reducing WASH-related mortality, and reducing the economic losses associated with inadequate access to improved water services. This conclusion painted a rather bleak picture for the continent. The results of the simulations we present here, however, tell a more nuanced story about sub-Saharan Africa's WASH future. Indeed, our forecasts suggest there is considerable heterogeneity in the trajectory of WASH-related mortality and economic losses.

Our simulations indicate that the majority of the population in sub-Saharan Africa lives in countries that are making only slow progress in reducing WASH-related mortality, and that the economic losses associated with inadequate access to improved water are likely to remain high well into the future. This includes countries that we identify as having high WASH-related mortality today and in the future (Group 1) as well as countries with moderate WASH-related mortality today that show only slow progress over the simulation period (Group 2). Even by 2050, WASH-related mortality in these countries is projected to remain above the level of WASH-related mortality in South Asia today. Although the economic losses associated with time spent collecting water outside the home increase in these countries over the simulation period, losses associated with WASH-related mortality and morbidity will continue to drive the total economic losses in these countries over the next three-and-a-half decades.

We also find, however, that some countries in sub-Saharan Africa will reduce the problem of WASH-related mortality and the economic losses associated with inadequate access to improved water supplies to very low levels by 2050. These are countries with low WASH mortality rates today, which decline to near zero levels before the end of the simulation period (Group 4) as well as countries that currently have moderate WASH mortality rates, but are projected to make rapid progress in reducing WASH-related mortality by 2050 (Group 3). Unfortunately, this good news comes from a limited number of countries that are home to only a small fraction of sub-Saharan Africa's total population. Additionally, while these countries will largely eliminate the health losses associated with inadequate access to improved water sources, economic losses associated with the time households spend collecting water will persist, and indeed will increase, until countries achieve universal access to piped or other in-home water supplies.

The results of our simulations have implications for the planning of WASH interventions in sub-Saharan Africa. Given the trends we forecast over the next three-and-a-half decades, how can the international community best target resources to countries that lag behind? Many countries in Group 2 have stable governments and emerging economies. However, countries with the highest WASH mortality rates and stagnant progress (Group 1) tend to have fragile governments and either weak economies or heavy reliance on mineral and oil exports. In our base case projections, these countries account for over 65 percent of the total WASH-related deaths in sub-Saharan Africa in 2050.

Additionally, our simulations highlight the importance of non-health benefits (e.g. the burden of time spent collecting water) associated with improved water supply. Even as countries reduce or eliminate the disease burden associated with inadequate access to water and sanitation infrastructure, WASH-related economic losses will persist as rising incomes increase the opportunity cost of time spent collecting water from outside the home. In these countries, policy-makers will need to pay careful attention to non-health benefits of improved water supply when evaluating investments to improve access to water and sanitation infrastructure. To our knowledge, however, there are few empirical estimates of the opportunity cost of time spent collecting water in sub-Saharan Africa that are needed to facilitate such investment analysis (see Cook et al., 2015). This is a clear area for future research.

Finally, we emphasise that there is nothing inevitable about the forecasts of WASH-related mortality and economic losses due to poor WASH conditions that are presented in this paper. These forecasts simply indicate the direction in which baseline economic growth and demographic drivers are leading coverage and mortality rates. Policy interventions and government commitment can influence these trajectories. But these forecasts are helpful for understanding the scale of the challenge and for focusing attention on where the challenge is likely to be greatest.

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Appendix 1. Summary of data on access to water sources in sub-Saharan Africa in 2015

	Improved			Unimproved		
Country	Total improved (%)	Piped on premises (%)	Other improved (%)	Total unimproved (%)	Other unimproved (%)	Surface water (%)
Angola	49.0	14.8	34.1	51.0	20.4	30.6
Benin	77.9	17.7	60.2	22.1	19.9	2.2
Botswana	96.2	74.4	21.8	3.8	1.9	1.9
Burkina Faso	82.3	8.0	74.3	17.7	14.3	3.4
Burundi	75.9	7.0	68.9	24.1	11.9	12.2
Cameroon	75.6	16.8	58.8	24.4	16.7	7.7
Cape Verde	91.7	59.4	32.3	8.3	8.2	0.1
Central African Republic	68.5	1.6	66.8	31.5	28.7	2.8
Chad	50.8	6.4	44.4	49.2	46.6	2.6
Comoros	90.1	38.0	52.1	9.9	9.9	0.0
Congo	76.5	24.8	51.7	23.5	14.3	9.2
Côte d'Ivoire	81.9	42.5	39.4	18.1	15.4	2.7
Democratic Republic of the Congo	52.4	7.9	44.6	47.6	36.4	11.2
Djibouti	90.0	52.7	37.3	10.0	9.3	0.7
Equatorial Guinea	47.9	10.3	37.5	52.1	38.9	13.2
Eritrea	57.8	9.2	48.5	42.2	27.2	15.0
Ethiopia	57.3	12.1	45.2	42.7	29.8	12.9
Gabon	93.2	64.5	28.7	6.8	2.2	4.6
Gambia	90.2	33.1	57.1	9.8	9.8	0.0
Ghana	88.7	18.9	69.8	11.3	7.6	3.7
Guinea	76.8	14.0	62.8	23.2	18.5	4.7
Guinea-Bissau	79.3	5.8	73.5	20.7	19.1	1.6
Kenya	63.2	21.7	41.5	36.8	14.9	21.9
Lesotho	81.8	22.3	59.5	18.2	17.8	0.5
Liberia	75.6	2.4	73.1	24.4	7.4	17.1
Madagascar	51.5	7.0	44.5	48.5	26.4	22.1
Malawi	90.2	7.9	82.3	9.8	8.8	1.0
Mali	77.0	15.9	61.1	23.0	21.6	1.3
Mauritania	57.9	32.6	25.3	42.1	40.7	1.4

Appendix 1. Summary of data on access to water sources in sub-Saharan Africa in 2015 (cont'd)

	Improved			Unimproved		
Country	**Total improved (%)**	**Piped on premises (%)**	**Other improved (%)**	**Total unimproved (%)**	**Other unimproved (%)**	**Surface water (%)**
Mauritius	99.9	99.8	0.0	0.1	0.1	0.0
Mozambique	51.1	8.6	42.4	48.9	37.5	11.5
Namibia	91.0	50.7	40.3	9.0	0.7	8.3
Niger	58.2	8.7	49.5	41.8	39.2	2.6
Nigeria	68.5	2.3	66.3	31.5	21.6	9.9
Réunion	99.1	99.1	0.0	0.9	0.9	0.0
Rwanda	76.1	9.2	66.9	23.9	15.2	8.7
Sao Tome and Principe	97.1	33.1	64.0	2.9	1.4	1.5
Senegal	78.5	53.1	25.4	21.5	20.8	0.7
Seychelles	95.7	93.7	2.0	4.3	0.5	3.8
Sierra Leone	62.6	5.4	57.3	37.4	16.5	20.8
Somalia	0.0	0.0	0.0	0.0	0.0	0.0
South Africa	93.2	72.7	20.5	6.8	4.3	2.5
South Sudan	58.7	1.8	56.9	41.3	17.1	24.2
Sudan	0.0	0.0	0.0	0.0	0.0	0.0
Swaziland	74.1	37.3	36.9	25.9	14.2	11.6
Togo	63.1	5.5	57.6	36.9	20.3	16.7
Uganda	79.0	5.0	74.0	21.0	12.9	8.1
United Republic of Tanzania	55.6	12.6	43.0	44.4	30.1	14.4
Zambia	65.4	15.8	49.6	34.6	22.7	12.0
Zimbabwe	76.9	27.5	49.4	23.1	17.0	6.1

Appendix 2. Summary of WASH mortality data (deaths per thousand)

Country	2002*	2004**	2008*	Country	2002*	2004**	2008*
Angola	3.27	3.22	3.01	Liberia	2.51	2.11	1.31
Benin	1.63	1.58	1.20	Madagascar	1.55	1.57	0.76
Botswana	0.23	0.25	0.27	Malawi	1.91	1.92	1.25
Burkina Faso	2.73	2.54	1.94	Mali	2.98	2.87	2.41
Burundi	1.92	1.89	1.84	Mauritania	1.21	1.13	1.06
Cameroon	1.40	1.32	1.48	Mauritius	0.01	0.01	0.02
Cape Verde	0.46	0.32	0.25	Mozambique	2.21	1.12	1.04
Central African Republic	1.48	1.48	1.37	Namibia	0.47	0.42	0.33
Chad	3.13	3.01	2.94	Niger	3.35	3.02	2.35
Comoros	0.86	0.65	0.89	Nigeria	1.69	1.60	1.41
Congo	0.63	0.52	0.76	Rwanda	1.51	1.44	1.32
Cote d'Ivoire	1.10	1.11	1.11	Senegal	0.77	0.72	0.64
Dem. Rep. of the Congo	2.76	2.60	2.24	Seychelles	0.02	0.02	0.02
Equatorial Guinea	1.04	1.40	1.05	Sierra Leone	2.42	2.15	1.62
Eritrea	0.95	0.88	0.63	Somalia	2.59	2.53	2.43
Ethiopia	1.68	1.66	1.62	South Africa	0.35	0.47	0.71
Gabon	0.37	0.36	0.41	Sudan	0.63	0.75	0.94
Gambia	0.84	0.87	0.80	Swaziland	0.73	0.58	0.52
Ghana	1.21	1.11	1.06	Tanzania	1.14	1.12	1.00
Guinea	1.47	1.41	1.27	Togo	1.25	1.21	0.85
Guinea Bissau	1.97	1.98	2.00	Uganda	1.21	1.26	1.35
Kenya	0.92	0.89	0.81	Zambia	1.95	1.51	1.40
Lesotho	0.81	0.68	0.43	Zimbabwe	0.78	0.78	0.49

* Calculated using the methodology from the WHO's Environmental Burden of Disease project.
** Obtained directly from WHO (2004).

Appendix 3. Summary of Jeuland et al. (2013a) forecasts of access to improved water sources and piped water compared with UNICEF and WHO (2015)

	Piped water		Improved water	
	|JMP data, previous forecast|	% Error	|JMP data, previous forecast|	% Error
Min	0.0	0	0.0	0
Max	27.7*	61	13.8	21
Mean	2.5	7	2.1	3
Median	1.4	4	1.1	1
Std Dev	3.72	10	2.64	4

* Bahrain

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