International Journal of Epidemiology, 2018, 740–751
doi: 10.1093/ije/dyx262
Advance Access Publication Date: 21 December 2017
Original article

Explaining Mortality Trends

Associations between key intervention coverage and child mortality: an analysis of 241 sub-national regions of sub-Saharan Africa

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Editorial decision 21 November 2017; Accepted 15 December 2017

Abstract

Background: Reducing child mortality remains a key objective in the Sustainable Development Goals. Although remarkable progress has been made with respect to under-5 mortality over the last 25 years, little is known regarding the relative contributions of public health interventions and general improvements in socioeconomic status during this time period.

Methods: We combined all available data from the Demographic and Health Survey (DHS) to construct a longitudinal, multi-level dataset with information on subnational-level key intervention coverage, household socioeconomic status and child health outcomes in sub-Saharan Africa. The dataset covers 562 896 child records and 769 region-year observations across 24 countries. We used multi-level multivariable logistics regression models to assess the associations between child mortality and changes in the coverage of 17 key reproductive, maternal, newborn and child health interventions such as bednets, water and sanitation infrastructure, vaccination and breastfeeding practices, as well as concurrent improvements in social and economic development.

Results: Full vaccination coverage was associated with a 30% decrease in the odds of child mortality [odds ratio (OR) 0.698, 95% confidence interval (CI) 0.564, 0.864], and continued breastfeeding was associated with a 24% decrease in the odds of child mortality (OR 0.759, 95% CI 0.642, 0.898). Our results suggest that changes in vaccination coverage, as well as increases in female education and economic development, made the largest contributions to the positive mortality trends observed. Breastfeeding was associated with child survival but accounts for little of the observed declines in mortality due to declining coverage levels during our study period.

Conclusions: Our findings suggest that a large amount of progress has been made with respect to coverage levels of key health interventions. Whereas all socioeconomic variables considered appear to strongly predict health outcomes, the same was true only for very few health coverage indicators.

Key words: Child mortality, health interventions, trend analysis, sub-Saharan Africa

Key Messages

- There was a generally positive trend in coverage of key health interventions, with substantial variations in absolute coverage levels within and across the 24 sub-Saharan countries over the past 25 years.
- Progress in coverage was particularly large for bednets, IPTp and PMTCT, and relatively modest for maternal education, water and sanitation.
- Urbanization, access to electricity and maternal education appear to have protective effects on child mortality.
- Only two of the 17 interventions considered, i.e. continued breastfeeding and full vaccination coverage, appear to be associated with child mortality in fully adjusted regression models controlling for socioeconomic factors.
- There was large heterogeneity in the impact of each intervention on child mortality across countries.

Introduction

Reducing child mortality remains one of the key objectives in the Sustainable Development Goals. Despite the remarkable progress made over the past 25 years, an estimated 5.9 million children under the age of five died in 2015, globally.[1–3]

The Millennium Development Goals have been credited with dramatically increasing investment in the health interventions necessary to meet global objectives, including investment towards a two-thirds reduction, between 1990 and 2015, in the under-five mortality rate.[4] In 2014, US$3.6 billion in development assistance for vaccinations was provided for low- and middle-income countries, more than four times the US$0.8 billion budget in 2000.[5] Similarly, between 2004 and 2009, international resources for malaria control increased from US$200 million to US$1.5 billion,[6] international HIV assistance increased from US$1.2 billion in 2002 to US$8.6 billion in 2014[7] and global commitments to water and sanitation increased from US$5.2 billion in 2000 to US$8.5 billion in 2009.[8]

The substantial increases in global health investment have led to large increases in the coverage levels of key interventions,[9,10] but little is known regarding the health impact of these recent efforts. A large body of experimental evidence has highlighted the effectiveness of targeted key interventions;[11–14] however, relatively little is known regarding the actual impact of the same interventions when rolled out at scale. Although considerable efforts have been made to more closely establish the levels and changes in the causes of under-five deaths,[2,15] few studies have attempted to measure the impact of recent efforts. Most available evidence focuses on either cross-country comparisons,[16–18] specific interventions[18,19] or within-country trend analysis.[20,21] This body of evidence is hard to interpret, not only due to the likely presence of salient cofounding concerns at the country level, but also because most programmes are not rolled out uniformly across countries and thus result in highly heterogeneous mortality changes.[22–25]

In this paper, we combine all available data from the Demographic and Health Survey (DHS) project to construct a longitudinal, multi-level dataset with information on key intervention coverage as well as child health outcomes across 241 subnational areas of sub-Saharan Africa over the period 1990 to 2014. The main objective of the paper is to estimate regional-level changes in intervention coverage as well as intervention-specific contributions to recent improvements in child mortality in sub-Saharan Africa. The focus on regions allows us to control for general country-specific changes; the panel structure of our data allows us to directly zoom in on changes within a region, controlling for all region-specific time-invariant factors.

Methods

Data

All data used in this paper are from the Demographic and Health Survey (DHS) programme. DHS surveys are nationally representative household surveys that provide data for a wide range of maternal and child health indicators.[26] We combined all available surveys conducted in sub-Saharan Africa between 1990 and 2014. Surveys before 1990 were excluded because they did not contain data on facility delivery, one of the key health services we assess in our analysis. Given our focus on changes over time, countries with only one available survey were excluded from final analysis. We extracted all individual child data from children born within 5 years of the survey. The number of child observations in a typical DHS dataset is around 7000, though there is variation in sample size across countries and time. These random samples are representative at the regional level, allowing us to compare country-region averages over time. We combined these regional averages over time to create a (pseudo-)panel dataset allowing longitudinal analysis with country and region fixed effects.

Surveys from Lesotho were dropped due to missing information on bednet coverage, and one survey from Cote d'Ivoire (2005) and one survey from Senegal (1997) were excluded because they did not contain vaccination data. Finally, the survey conducted in Benin from 2006 was excluded because it was missing data on household electricity. The final dataset covers 769 region-year observations across 24 countries. A full list of all 78 surveys included is available in Appendix Table A1, available as Supplementary data at *IJE* online.

Spatial aggregation

In order to have comparable subnational measures of intervention coverage over time, country-specific region definitions were created for this project. All DHS surveys are designed to be representative at the regional level and explicitly use stratified sampling to cover regional areas (most typically provinces or states) identified for each survey. In many cases, geographical strata and regions change over time due to changes in administrative boundaries or changes in the overall sampling approach. When regional definitions differed across survey years, we used the smallest unit-identifiable region across all survey rounds. In many cases, earlier regions were divided into sub-regions in later rounds—in these cases, we used the original region definition across all rounds, i.e. combined smaller sub-regions used in later rounds into the larger original regions. Our recoding resulted in a total of 241 regions across the 24 sample countries, shown in Appendix Table A2 (available as Supplementary data at *IJE* online). Figure 1 illustrates the overall spatial coverage of the dataset.

Outcome measure

The primary outcome was the probability of death of children under the age of 5 years. As part of DHS protocols, mothers are asked to list all children ever born alive. In our analysis, we focused on children born within the 5 years preceding the survey. The outcome was coded as zero if the child was still alive at the time of the survey, and 1 if the child had passed away. Since exposure time varies across children, we controlled for exposure time (years since birth) in our empirical models. To keep the timing of intervention coverage as close as possible to the timing of death, we restricted our analysis to children born in the 5 years preceding the interview in our empirical analysis.

Public health interventions considered

We considered an extensive list of factors contributing to child mortality decline. To be systematic in our selection of interventions, we referenced the Countdown to 2015 Maternal, Newborn, and Child Survival Commission's indicators (the 2012 Report, *Building a Future for Women and Children*, Annex B: Definitions of Countdown indicators) and used the respective definitions to estimate the intervention coverage with available DHS data. The primary public health interventions covered in DHS are bednet coverage for malaria prevention, water and sanitation infrastructure, vaccination coverage, institutional deliveries, modern contraceptive usage, antenatal care (ANC), neonatal tetanus protection, low body mass index (BMI), intermittent preventive treatment for malaria during pregnancy (IPTp), caesarean section rate (C-section), oral rehydration therapy (ORT) and breastfeeding practices.

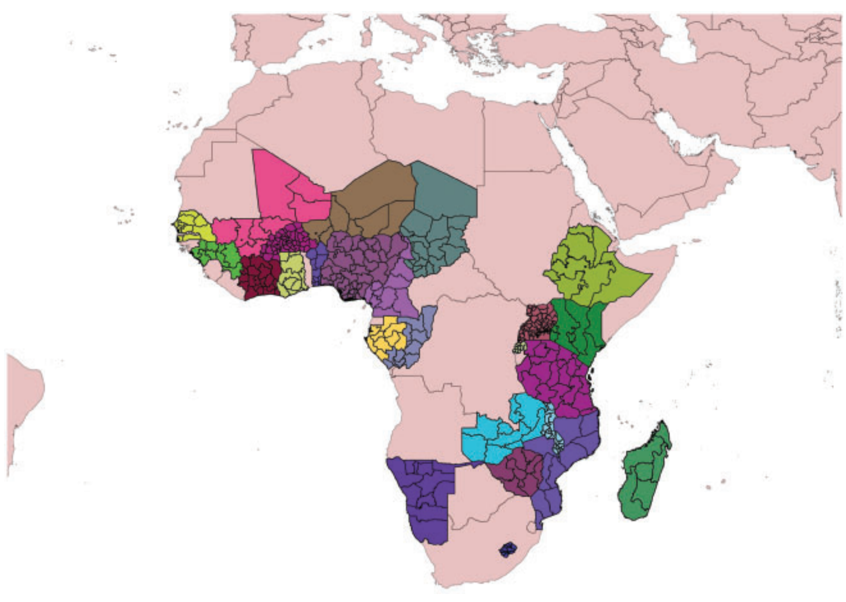

Figure 1. Spatial coverage of analytical sample.

Antibiotic treatment for pneumonia and antimalarial treatment were not included in the analysis due to missing data (74% and 10% missing as regional coverage estimates, respectively). Bednet use as measured by report of having a bednet for sleeping was missing for 38% of country region-years, with the majority of missing data from earlier survey years. We therefore used bednet coverage from the nearest survey to obtain a complete measure for this variable. Adapting the WHO/UNICEF Joint Monitoring Program, we divided water and sanitation facilities into high and low quality access. For high quality water, we included a binary measure of piped water availability in the household.

A second variable measured the use of water collected from a well or borehole, which was considered intermediate quality in this analysis. High quality sanitation was coded as any form of flush toilet. All other forms of household latrine access were coded as intermediate quality sanitation. Modern family planning was considered to be current maternal use of any of the following methods: female sterilization, male sterilization, the pill, the intrauterine device (IUD), injectables, implants (such as Norplant), the female condom, the male condom, lactational amenorrhoea method (LAM), emergency contraception, the diaphragm and foam/jelly. Low body mass index was defined as percentage of mothers with a body mass index of less than 18.5 kg/m^2. Children whose mothers received at least one ANC visit were recorded as having had ANC.

Newborns were considered to be protected against tetanus when their mothers received two doses of tetanus toxoid vaccine within the appropriate interval before the infant's birth. IPTp coverage was defined as the percentage of children whose mothers received IPTp during their pregnancy. C-section coverage was defined as the percentage of live births delivered by C-section. Breastfeeding practices were measured using two variables based on the WHO recommendation to exclusively breastfeed infants for the child's first 6 months, and thereafter to continue breastfeeding up to the age of 2 years or beyond with nutritious complementary foods.[27]

The first variable was an indicator of the duration of breastfeeding, and was calculated by measuring whether children between 18 and 24 months of age were still being breastfed at the time of the survey. The second variable was an indicator for exclusive breastfeeding. It measured whether children who were less than 6 months old at the time of the survey were both being breastfed and had not received water in the 24-h period preceding the survey interview. Children over age 1 year, with documented receipt of measles, Bacille Calmette-Guerin (BCG), diphtheria, tetanus and pertussis (DTP3) and polio vaccines were considered to have been fully vaccinated. Women having delivered in a public or private sector health facility were considered to have had a safe delivery with skilled attendance at birth. Among children with diarrhoea in the 2 weeks before the survey, the percentage of those who received ORT was used to estimate the ORT coverage. With the exception of HIV prevalence and coverage of prevention of mother-to-child transmission of HIV (PMTCT), regional intervention levels were calculated as the mean of each intervention variable in a given region during a given survey year. Because the underlying household variables were all dichotomous, these mean values directly correspond to the percentages of households surveyed with a given exposure or outcome. An intervention coverage of 0 thus means that 0% of children benefited from a given intervention, and a coverage of 1 means that every child benefited.

The child DHS files did not include data on HIV prevalence and PMTCT, two variables that affect child survival. The DHS began conducting separate surveys that measure population HIV prevalence in the early 2000s. We used data from DHS reports on the prevalence of HIV by region, to add HIV prevalence data to the dataset. DHS HIV data were available for 19 countries from at least 1 year, and 14 countries had 2 years of HIV data. To measure HIV prevalence, we calculated regional-level averages over time using HIV prevalence data from DHS surveys when available. For survey years for which no DHS data were available, we used data on changes in country-level prevalence from UNAIDS to calculate an estimated regional prevalence.[28] When no DHS data were available, as was the case for Benin, Chad, Madagascar, Namibia and Nigeria, we used UNAIDS annual prevalence from each survey year to create a country average that was used for all county-region years. We used PMTCT estimates from the UNAIDS 2013 progress report on the global plan towards the elimination of new HIV infections among children by 2015 and keeping their mothers alive.[29] This report contained data on the percentage of HIV-positive women receiving anntiretrovirals (ARVs) to prevent mother-to-child transmission in 2009 and 2012, from 14 high-prevalence counties. To create a PMTCT variable for analysis, we assumed that there was little or no PMTCT coverage before 2004 and that the coverage was linearly increasing between 2004 and 2009, and between 2009 and 2012. Countries without PMTCT data collected by UNAIDS were assumed to have no PMTCT coverage; we included a binary indicator for missing PMTCT data in our empirical model, to ensure that our estimates were not affected by this assumption.

All children under 5 years of age were included in the regional-level coverage estimates for most variables. Due to the timing of vaccination schedules, however, very young children are not yet eligible for some vaccinations and thus not relevant for regional-level coverage. Therefore, only children who were at least 12 months old when surveyed were included when calculating regional-level vaccine coverage. Further, age was restricted for both breastfeeding variables. For the variable measuring at least 18 months to 24 months of breastfeeding, only children between 18 and 24 months of age were included in the coverage calculation. For the variable measuring exclusive breastfeeding, only infants under 6 months of age were included in the calculation. Only children who experienced diarrhoea in the 2 weeks before the survey were included to calculate ORT coverage. For maternal health interventions such as ANC and low BMI, the coverage among mothers of all individual children included in the analysis was used; thus the unit was at child level and not at the individual mother level.

There are many other public health interventions, such as iron folic acid in pregnancy, that are associated with reduced neonatal and child mortality in specific settings. It was, however, not possible to consider all potential factors; the focus of this paper was to assess the most critical interventions identified by the Countdown.

Statistical analysis

To estimate the associations between intervention coverage and child mortality, we estimated the following multi-level model:

$$CM_{irct} = \alpha + \beta X_{irct} + \gamma I_{rct} + \delta_r + \delta_{ct} + \varepsilon_{irct}$$

CM is a binary indicator for whether or not child i from region r in country c and period t has died by the time of the interview. I_{rct} is a vector of intervention coverage variables for the respective region, and δ_r, δ_{ct} are region- and country-survey-year fixed effects. X_{irct} X_{irct} is a vector of individual-level controls including maternal education level, urban residence and household electricity, child age and gender and maternal risk factors. We used multivariable logistic models as our main specifications, and showed alternative ordinary least squares (OLS) regressions in the Appendix, available as Supplementary data at *IJE* online.

In our fully adjusted empirical model, we controlled for both initial regional differences and aggregate changes at the country level through region and survey fixed effects, and thus exclusively explore differences in coverage and health outcomes observed within each country across regions. The main advantage of this specification was that we could rule out confounding through time-invariant regional factors such as climate or infrastructure, as well as confounding through country-specific events such as political instability, drought or general economic policy and progress. The disadvantage of this approach is that fixed effects absorb a substantial amount of variation, which then cannot be attributed to any particular factor in our decomposition analysis. To quantify the relative contribution of each risk factor, we multiplied average county-level changes in intervention coverage between the first and the last included survey, with the estimated coefficients from our fully adjusted multivariable OLS models. These linear probability (OLS) models directly estimated mean mortality differentials, which we then multiplied by linear coverage changes to obtain aggregate change estimates. We used the Stata 14 statistical software package.

Results

Table 1 summarizes key variables in the final analytical dataset. There were a total of 562 896 child records across all regions and time periods and an average of 2336 individual children per region, with a minimum regional sample of 442 and maximum regional sample size of 21 820 children. For our analysis, the primary unit of interest was the child; children can share the same mother, household and regional coverage. As Table 1 shows, the study sample was mostly rural, with only 27% of children living in urban households and 20% of households reporting access to electricity; 47% of mothers had no education and 37% had primary education. On average, 97 out of 1000 live births had died by the time of the survey.

43% of sample households owned a bednet; access to high quality sanitation as measured by household use of a flush toilet was only 9%, and the piped water access was only 28%. In all, 65% of children were fully vaccinated, 48% of women delivered in facilities, 18% of women reported using modern contraceptives at the time of the survey and 87% of women had at least one ANC visit during their most recent pregnancy. 49% of children were breastfed for at least 18 months to 24 months, and 36% of children under 6 months of age were exclusively breastfed at the time of the survey. The correlation among these interventions was generally very low, was shown in Appendix Table A3, available as Supplementary data at *IJE* online.

Table 2 and Figure 2 show the coverage levels for the first and the last surveys for the 24 countries, including median, mean, minimum and maximum. Coverage levels of all key interventions improved over time except for continued breastfeeding, which declined from a mean coverage of 51.9% to a mean coverage of 46.3% over the sample period. The percentage of mothers without education decreased from 47.4% to 42.5%, and mothers with secondary and higher education increased from 16.25% to 21.5%. Access to electricity improved from 18.8% to

Table 1. Summary statistics for individual and regional level variables from Demographic and Health Surveys, sub-Saharan Africa, 1991–2013

Individual level variables (n = 562896)	
Child	
Child death n (%)	54383 (9.7)
Child's age (months) mean (SD)	28.0 (17.1)
Child is male n (%)	278377 (49.5)
Multiple birth n (%)	19666 (3.5)
Mother	
Mother's age (years) mean (SD)	28.7 (7.0)
Maternal education	
No education n (%)	264949 (47.1)
Primary education n (%)	207626 (36.9)
Secondary or higher education n (%)	90321 (16.0)
Teenage mother n (%)	39017 (6.9)
Household	
Electricity n (%)	109563 (19.5)
Urban n (%)	149367 (26.5)
Regional level variables[a] (n = 769)	
Bednet in home mean (SD)	0.43 (0.283)
High quality sanitation mean (SD)	0.085 (0.157)
Intermediate quality sanitation mean (SD)	0.572 (0.295)
High quality (piped) drinking water mean (SD)	0.283 (0.25)
Intermediate quality water source mean (SD)	0.429 (0.262)
Modern family planning mean (SD)	0.176 (0.16)
Low maternal BMI (SD)	0.088 (0.073)
At least 1 ANC visits mean (SD)	0.869 (0.172)
Neonatal tetanus protection mean (SD)	0.622 (0.169)
IPTp mean (SD)	0.217 (0.253)
Delivered in a health facility mean (SD)	0.484 (0.257)
C-section mean (SD)	0.036 (0.038)
Exclusive breastfeeding among infants < 6 months mean (SD)	0.359 (0.268)
Children breastfed until at least 18–24 months mean (SD)	0.488 (0.211)
Child fully vaccinated mean (SD)	0.646 (0.238)
Received polio vaccine mean (SD)	0.845 (0.156)
Received DPT vaccine mean (SD)	0.77 (0.218)
Received BCG vaccine mean (SD)	0.809 (0.203)
Received measles vaccine mean (SD)	0.709 (0.217)
Oral rehydration therapy mean (SD)	0.35 (0.213)
PMTCT coverage mean (SD)	0.06 (0.148)

[a]All children under 5 years of age were included in the regional level coverage estimates except for full vaccination (only 1 year old and above), exclusive breastfeeding (below 6 months old), continued breastfeeding (18–24 months old), and PMTCT (separate data source).

24.9%. Urbanization was stagnant in terms of means, but this is likely due to DHS sampling methods. Figure 2 illustrates the levels of mortality and the key health intervention coverage between the first and last surveys for countries included in the analysis. Observed child mortality declined from 105 per 1000 live births to 77 per 1000 live births between the first and the last surveys. Substantial increases in coverage were found for bednet ownership, vaccination, use of modern family planning and ANC. Appendix Table A4 (available as Supplementary data at *IJE* online) shows in further detail the mean probability of child death and intervention coverage levels for the first and last survey by country.

Table 3 presents the results from our logistic regressions. Unadjusted estimates in column 1 were obtained from individual bivariate regression models for each intervention without controls. Adjusted estimates in column 2 controlled for other interventions and SES (socioeconomic status) and included all interventions in the same model. Finally, the fully adjusted models in column 3 controlled for all interventions and region and country-survey-year fixed effects. In the bivariate regression models, all but one intervention (intermediate quality sanitation) showed *P*-values of less than 0.05, and all of the interventions except for intermediate quality water and breastfed for 18–24 months were negatively associated with child mortality. A total of 13 of the 17 interventions displayed *P*-values of less than 0.05 in the associations with child mortality in the adjusted specification, which included only controls for other interventions and SES. In the fully adjusted specification which controlled for SES and regional and survey fixed effects, only two interventions showed *P*-values of less than 0.05 in the associations: continued breastfeeding and full vaccination coverage: Continued breastfeeding was associated with a 24% decrease in the odds of child mortality (OR 0.759, 95% CI 0.642, 0.898). Full vaccination coverage was associated with a 30% decrease in the odds of child mortality (OR 0.698, 95% CI 0.564, 0.864). In the same model using OLS regressions, ANC and IPTp showed *P*-values less than 0.05 in addition to continued breastfeeding and full vaccination coverage (Appendix Table A5, available as Supplementary data at *IJE* online).

Table 4 shows the estimated contributions of each factor to the observed decline in mortality. In order to compute mean effects, estimated linear associations in column 1 were multiplied with average increases in coverage (column 4). Appendix Table A5 shows the full details of the multivariate OLS models. The largest contributions were found for ANC, IPTp and full vaccination coverage, with attributed mortality reductions of 3.85, 6.38 and 2.99 deaths before age five per 1000 live births, respectively. Although continued breastfeeding was found to be protective for mortality, continued breastfeeding did not contribute to the aggregate improvements in mortality over the sample period, due to the observed 5.6 percentage point decline in breastfeeding practices over time. This resulted in the negative (-1.01) net contribution of breastfeeding to the observed mortality decline. The impact of PMTCT was estimated to be high, but was estimated with very large standard errors. Higher

Table 2. Country level median and mean intervention coverage levels for the first and last survey from each of the 24 countries included

Intervention	First surveys		Last surveys		Change in coverage	
	Mean (median) coverage	Range (minimum, maximum)	Mean (median) coverage	Range [minimum, maximum]	Change in median coverage (%)	Change in mean coverage (%)
% Bednets coverage	38.7 (35.4)	(3.8,81.1)	66.2 (73.5)	(14.7, 89.9)	38.1	27.5
% High quality sanitation	6.6 (2.2)	(0, 31.4)	8.1 (6.1)	(0.7, 28.8)	3.9	1.5
% Intermediate quality sanitation	52.1 (49.0)	(10.0, 93.0)	57.1 (59.8)	(8.5, 95.7)	10.8	5.0
% High quality (piped) drinking water	28.4 (25.0)	(7.0, 64.0)	29.8 (28.0)	(8.8, 71.5)	3.0	1.4
% Intermediate quality water source	40.7 (42.2)	(0.9, 76.0)	47.3 (49.5)	(9.8, 76.7)	7.3	6.6
% Modern contraceptive use	11.2 (8.1)	(1.9, 47.1)	21.2 (16.3)	(5.5, 61.0)	8.2	10.0
% Low maternal BMI	9.8 (9.2)	(0, 25.4)	8.2 (6.6)	(2.1, 25.1)	−2.6	−1.6
% At least 1 ANC visit coverage	80.1 (85.1)	(37.3, 96.4)	91.1 (93.9)	(64.7, 99.0)	8.8	11.0
% Neonatal tetanus protection	52.9 (52.2)	(18.5, 100.0)	68.1 (69.5)	(51.6, 80.4)	17.3	15.2
% IPTp	13.4 (2.4)	(0.01, 69.9)	38.9 (40.6)	(0.6, 87.9)	38.2	25.5
% Safe delivery coverage	46.7 (44.7)	(10.8, 84.0)	52.3 (54.2)	(15.7, 86.9)	9.5	5.6
% C-section	3.2 (2.7)	(0.6, 12.5)	3.9 (4.0)	(0.7, 11.5)	1.3	0.7
% Breastfed for at least 18-24 months	51.9 (55.7)	(11.8, 80.4)	46.3 (48.9)	(7.4, 72.3)	−6.8	−5.6
% Exclusively breastfed for 6 months	26.2 (13.5)	(0.0, 95.8)	41.6 (37.7)	(13.8, 81.7)	24.2	15.4
% Full vaccination coverage	60.4 (62.3)	(25.6, 90.2)	69.2 (72.5)	(25.7, 92.6)	10.2	8.8
% ORT coverage	32.7 (28.3)	(6.6, 80.9)	35.8 (31.7)	(11.8, 71.3)	3.4	3.1
% PMTCT	0 (0)	(0, 0)	18.8 (0)	(0, 62.0)	0.0	18.8
% No education	47.4 (40.7)	(6.3, 87.5)	42.5 (31.2)	(1.9, 84.9)	−9.5	−4.9
% Primary education	36.4 (36.3)	(8.5, 63.1)	35.9 (32.1)	(10.0, 69.9)	−4.2	−0.5
% Secondary or higher education	16.2 (7.1)	(2.0, 56.9)	21.5 (13.9)	(4.7, 64.8)	6.8	5.3
% Electricity	18.8 (12.0)	(4.2, 64.9)	24.9 (20.2)	(5.0, 75.1)	8.2	6.1
% Urban	31.0 (28.1)	(10.9, 61.6)	28.7 (28.8)	(9.5, 61.6)	0.7	−2.3

maternal education (secondary and higher) was associated with a 1.22 reduction in mortality, and access to electricity contributed a 0.79 reduction in child mortality.

Regarding ANC, we initially included an indicator of having received four or more visits during pregnancy (ANC4), but due to the fact that we needed to separately categorize women who never attended ANC, those who had 1-3 visits, those who had more than 4 visits and those who had an extremely high number of visits (indicating high-risk pregnancy), we ultimately decided that the simplest indicator of 1 ANC or more was more appropriate in our analysis. We also used ANC4+ versus all others, and the results of the OLS regressions are shown in Appendix Table A6, available as Supplementary data at *IJE* online.

The main objective of this paper was to quantify the relative contributions to mortality in the under-five age range overall, without a particular focus on specific ages within the 5 years. Regardless, we were still interested in whether the results would differ by specific age groups; therefore we estimated separate contributions for the neonatal, post-neonatal, infancy and post-infancy child periods. The results of these estimates are shown in Annex Tables A7, A8, and A9, available as Supplementary data at *IJE* online.

Discussion

The results presented in this paper suggest that increased coverage of key interventions has made a substantial contribution to the recent decline in under-five mortality in sub-Saharan Africa. The largest effects were found for improved coverage of ANC, IPTp and vaccinations. Whereas we found positive associations between most other interventions and child survival, no associations under the *P*-value of 0.05 were found for water and sanitation infrastructure or neonatal tetanus protection. Continued breastfeeding was found to be protective against child mortality, but had a negative contribution overall due to the decline in coverage observed over the sample period. The forest plots of the adjusted association of changes in intervention coverage on child mortality are shown for each intervention by country in Appendix Figures A1-A19, available as Supplementary data at *IJE* online. These figures show how heterogeneous the effects are for many of the interventions.

The under-five mortality rate has declined from an estimated rate of 91 deaths per 1000 live births in 1990 to 43 deaths per 1000 live births in 2015 globally.[30] The mortality decline we observed from our data is about 30 per 1000 live births (from 0.10 to 0.07). Of these 30 deaths per

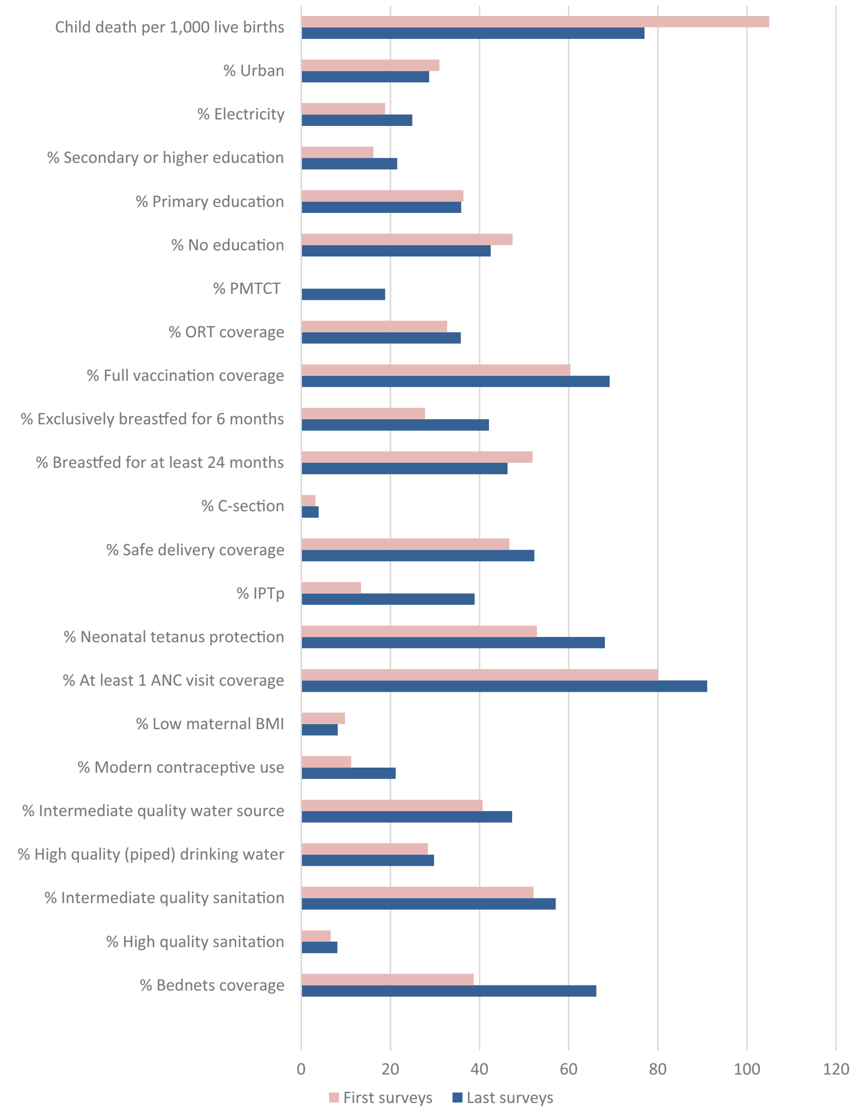

Figure 2. Levels in mortality and intervention coverage between the first and last surveys (all countries pooled).

1000, our estimates suggest that 4.52, 6.38, and 2.99 avoided deaths per 1000 can be attributed to increased ANC coverage, increased IPTp coverage, and increased vaccination coverage respectively, and 1.22 and 0.79 avoided deaths can be attributed to higher maternal education and electricity respectively. ANC, IPTp and vaccination alone contributed nearly half of the child mortality decline we observed in the regions over the past two decades.

The overwhelming majority of changes measured in our data can be attributed to general trends, which likely capture a large range of factors including improving general living conditions, higher quality of care and other changes in government policies and infrastructure. From a historical perspective, mortality decline in Europe and North America went hand in hand with economic development and the accompanying advances in public infrastructure such as water and sanitation. In sub-Saharan Africa, however, the pattern appears different; though annual gross domestic product (GDP) growth has been moderate since the early 2000s, sub-Saharan Africa is the only region in the world for which the number of poor individuals has risen steadily and dramatically between 1981 and 2010.[31,32] It thus seems unlikely that overall improvements observed can largely be attributed to improved economic development.

The fact that increased ANC and vaccination coverage accounted for substantial proportion of the mortality decline may not come as a great surprise, and the same is true for education and general economic development. More surprising is the fact that we did not find an effect for some interventions for which coverage has changed dramatically, and which have been shown to have strong effects on child survival. This is maybe most striking for bednets, where coverage has increased tremendously in

Table 3. Multivariable logistic regression results $n = 562896$

Variable	Unadjusted associations			Adjusted for other intervention coverage			Fully adjusted associations with fixed effects		
	Odds ratios	95% CI		Odds ratios	95% CI		Odds ratios	95% CI	
% Bednets coverage	0.743***	(0.720	0.766)	0.870***	(0.830	0.911)	1.054	(0.887	1.252)
% High quality sanitation	0.345***	(0.316	0.377)	1.376***	(1.211	1.563)	0.857	(0.600	1.223)
% Intermediate quality sanitation	0.986	(0.957	1.017)	1.281***	(1.233	1.331)	0.995	(0.828	1.195)
% High quality (piped) drinking water	0.481***	(0.460	0.502)	0.888**	(0.822	0.959)	0.828	(0.675	1.017)
% Intermediate quality water source	1.621***	(1.567	1.677)	1.167***	(1.104	1.233)	0.868	(0.733	1.028)
% Modern contraceptive use	0.286***	(0.267	0.306)	0.586***	(0.525	0.653)	1.263	(0.954	1.672)
% Low maternal BMI	3.211***	(2.843	3.627)	0.477***	(0.402	0.566)	1.353	(0.840	2.182)
% At least 1 ANC visit coverage	0.388***	(0.370	0.406)	0.732***	(0.650	0.825)	0.861	(0.619	1.198)
% Neonatal tetanus protection	0.365***	(0.346	0.385)	0.739***	(0.664	0.822)	0.814	(0.596	1.113)
% IPTp	0.648***	(0.627	0.669)	1.054*	(1.002	1.108)	0.802	(0.615	1.047)
% Safe delivery coverage	0.442***	(0.427	0.458)	0.746***	(0.695	0.800)	1.017	(0.781	1.324)
% C-section	0.0005***	(0.0003	0.0007)	0.210***	(0.121	0.365)	1.175	(0.453	3.049)
% Breastfed at least 18-24 months	1.807***	(1.722	1.896)	0.983	(0.914	1.057)	0.759**	(0.642	0.898)
% Exclusively breastfed for 6 months	0.747***	(0.724	0.771)	0.767***	(0.732	0.803)	1.027	(0.861	1.226)
% Full vaccination coverage	0.560***	(0.539	0.581)	1.015	(0.945	1.091)	0.698***	(0.564	0.864)
% ORT coverage	0.648***	(0.618	0.678)	1.039	(0.972	1.110)	1.005	(0.854	1.183)
% PMTCT coverage	0.500***	(0.472	0.531)	0.981	(0.898	1.073)	0.285	(0.015	5.396)
% Primary education	0.964***	(0.947	0.982)	0.942***	(0.920	0.964)	0.941***	(0.918	0.964)
% Secondary and higher education	0.589***	(0.573	0.606)	0.723***	(0.698	0.749)	0.719***	(0.693	0.746)
% Electricity	0.633***	(0.617	0.649)	0.808***	(0.782	0.834)	0.823***	(0.796	0.851)
% Urban	0.765***	(0.749	0.781)	0.959**	(0.934	0.984)	0.918***	(0.894	0.944)
% Teenage mother	1.150***	(1.112	1.188)	1.488***	(1.437	1.540)	1.495***	(1.444	1.548)

We describe the construction of all exposure variables in the Methods section. All explanatory variables were standardized on a 0-1 scale, where 0 means that the 0% of children benefited from the intervention, and 1 means that every child benefited. Unadjusted estimates control for intervention coverage only; each coefficient comes from a separate bivariate regression model. Adjusted estimates include all interventions in the same model. Fully adjusted models in addition control for region- and country-survey-year fixed effects. By intervention we mean both the sociodemographic variables and the health interventions here.

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

recent years. One reason that may explain why bednet coverage was not shown to be effective in our analysis could be that coverage increased more uniformly within countries (e.g. via mass distribution campaigns) compared with other interventions requiring greater health service infrastructure such as ANC and vaccination. If this were the case, our study design, which relied on within-country variation over time, would not detect any positive effect of bednets. It is also possible that reported bednet ownership is a poor indicator of whether children consistently sleep under the net.

Having a highly educated mother will increase children's chances of survival from conception to age five, and thus likely will have a stronger association with child mortality than a single age-specific intervention such as institutional deliveries. More generally, each intervention primarily targets one cause of death, whereas socioeconomic factors likely affect most, or at least an extensive number of factors.

We think that the empirical model presented in this paper provides a first and important test for the effectiveness of key public health interventions at scale, but our work has several important limitations. First, as mentioned above, our final model included both the region- and country-survey-year fixed effects in addition to individual socioeconomic controls. The inclusion of survey fixed effects absorbs all country-level trends over time, and thus also the average improvements in intervention coverage. This works well in settings where programmes have regional focus, or at least show substantial regional variations in coverage. If intervention coverage increases uniformly at the country level, all of the improvements are absorbed by the country-specific time trends, essentially reducing the net variation in our exposures of interest to a minimum. This may be particularly problematic in the context of the aforementioned large bednet distribution or mass vaccination efforts, which have an explicit national focus.

We also did not take into account the disease burden within each region before intervention rollout. In practice, health interventions are not rolled out randomly, and are often placed in areas where the expected impact is the

Table 4. Observed change in intervention coverage and estimated contribution to child mortality

	Estimated linear impact of factor on mortality		Observed absolute change in coverage	Estimated contribution to child mortality (per 1000 live births)	
	Beta	95% CI	% point increase	Deaths per 1000 live births)	95% CI
	(1)	(2)	(3)	(4)	(5)
% Bednets coverage	0.003	(−0.012, 0.017)	27.5	0.83	[−3.3, 4.68]
% High quality sanitation	−0.008	(−0.035, 0.02)	1.5	−0.12	[−0.53, 0.3]
% Intermediate quality sanitation	−0.002	(−0.017, 0.013)	5.0	−0.10	[−0.85, 0.65]
% High quality (piped) drinking water	−0.012	(−0.029, 0.005)	1.4	−0.17	[−0.41, 0.07]
% Intermediate quality water source	−0.012	(−0.026, 0.002)	6.6	−0.79	[−1.72, 0.13]
% Modern contraceptive use	0.023	(−0.001, 0.046)	10.0	2.30	[−0.1, 4.6]
% Low maternal BMI	0.031	(−0.01, 0.072)	−1.6	−0.50	[0.16, −1.15]
% At least 1 ANC visit coverage	−0.035	(−0.063, −0.007)	11.0	**−3.85**	**[−6.93, −0.77]**
% Neonatal tetanus protection	−0.007	(−0.032, 0.019)	15.2	−1.06	[−4.86, 2.89]
% IPTp	−0.025	(−0.046, −0.004)	25.5	**−6.38**	**[−11.73, −1.02]**
% Safe delivery coverage	0.000	(−0.021, 0.021)	5.6	0.00	[−1.18, 1.18]
% C-section	0.046	(−0.03, 0.122)	0.7	0.32	[−0.21, 0.85]
% Breastfed at least 18-24 months	−0.018	(−0.032, −0.005)	−5.6	1.01	[1.79, 0.28]
% Exclusively breastfed for 6 months	0.004	(−0.011, 0.018)	15.4	0.62	[−1.69, 2.77]
% Full vaccination coverage	−0.034	(−0.051, −0.016)	8.8	**−2.99**	**[−4.49, −1.41]**
% ORT coverage	−0.002	(−0.015, 0.012)	3.1	−0.06	[−0.47, 0.37]
% PMTCT coverage	−0.105	(−0.266, 0.056)	18.8	−19.74	[−50.01, 10.53]
% Primary education	−0.006	(−0.008, −0.004)	−0.5	0.03	[0.04, 0.02]
% Secondary and higher education	−0.023	(−0.026, −0.02)	5.3	−1.22	[−1.38, −1.06]
% Electricity	−0.013	(−0.016, −0.011)	6.1	−0.79	[−0.98, −0.67]
% Urban	−0.007	(−0.009, −0.005)	−2.3	0.16	[0.21, 0.12]

Columns 1 and 2 show estimated coefficient from a linear multivariable model; the full model underlying these estimates is shown in Appendix Table A5, available as Supplementary data at *IJE* online. Column 3 shows mean absolute changes in coverage. Column 4 shows estimated total impact (column 1 multiplied by column 3). Column 5 shows 95% confidence intervals. Bolded numbers represent positive contributions with P-values < 0.05.

largest, or in places where specific diseases are of high priority. This non-random placement may inflate estimated impacts if programmes are placed in settings with particularly high impact, and may attenuate observed impacts if programmes are placed in settings where the potential improvements are limited. There are other elements of health care that are critical in determining health outcomes, such as the performance of health systems and quality of care, which were not taken into account in our analysis. PMTCT was included but, with its limited coverage, it did not function as a measure of health system quality, as it could also simply be a vertical programme to ANC.[33] It is important to also note that coverage, as measured by having access to an intervention, does not imply that the intervention is used consistently or is of high quality. For example, households who have access to high quality sanitation may not consistently use this service.

Finally, our variable definitions may not always perfectly measure the interventions of interest, due to measurement error and data availability. For example, our exclusive breastfeeding variable is less restrictive than the World Health Organization's definition, which defines exclusive breastfeeding as 'no other food or drink, not even water, except breast milk (including milk expressed or from a wet nurse) for 6 months of life'.[34] We restricted our variable definition based on water consumption only because data availability on other liquids and foods differed across the surveys included in our analysis. Water consumption has been identified as the largest obstacle to exclusive breastfeeding,[35] and we expect that only a very small proportion of infants meeting our study definition consumed other liquids and foods in the previous 24 h. Although our breastfeeding measure will on average overstate the true degree of exclusive breastfeeding, it should still allow us to capture changes in this practice over time.

Overall, the estimates presented likely represent a lower bound to the true impact that recent global health efforts have had on child survival. Even if one took these numbers at their face value, the overall cost-effectiveness of current effort can hardly be questioned. The current estimate of child mortality for sub-Saharan Africa is about three million deaths per year. An additional three million children would likely die in sub-Saharan Africa today if the under-5 mortality rates had not changed since 1990.[1–3] We can directly attribute 50% of this mortality reduction to key interventions.

Development assistance for health has been growing over recent decades, with donors disbursing a total of US$31.3 billion to improve health in low- and middle-income countries in 2013, a 5-fold increase compared with 1990.[35] Among the health focus areas, the share of funding that targets maternal, newborn and child health has continued to grow. Building upon the various resource tracking efforts on maternal, newborn and child health,[35,36] the next question we need to ask is whether the money is going to interventions that do effectively contribute to mortality decline. The results presented in this paper suggest that there are substantial differences in the effectiveness of programmes at scale.

Conclusion

The results of this paper suggest that expanded coverage of public health interventions has made a substantial contribution to the mortality decline observed in sub-Saharan Africa over the past 25 years. Whereas all socioeconomic variables considered appear to strongly predict health outcomes, the same was true only for very few health coverage indicators. These weak results may reflect a certain extent of measurement error, but could also be interpreted as evidence of limited intervention effectiveness at scale. Further research should be pursued to more closely identify whether sufficient investments have been made to support effective interventions, and why specific interventions may or may not work in specific settings.

Supplementary Data

Supplementary data are available at *IJE* online.

Funding

This work was supported by the Global Fund to Fight AIDS, Tuberculosis and Malaria and United Nations University, World Institute for Development Economics Research (UNU-WIDER).

Conflict of interest: None declared.

Acknowledgements

We thank the editor, the anonymous referees, Dr Agbessi Amouzou, Dr Kenneth Hill and the participants at the 2016 PAA Annual Meetings Session 158 for their valuable comments.

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