

An exploration of multilevel modeling for estimating access to drinking-water and sanitation

Jennyfer Wolf, Sophie Bonjour and Annette Prüss-Ustün

ABSTRACT

Monitoring progress towards the targets for access to safe drinking-water and sanitation under the Millennium Development Goals (MDG) requires reliable estimates and indicators. We analyzed trends and reviewed current indicators used for those targets. We developed continuous time series for 1990 to 2015 for access to improved drinking-water sources and improved sanitation facilities by country using multilevel modeling (MLM). We show that MLM is a reliable and transparent tool with many advantages over alternative approaches to estimate access to facilities. Using current indicators, the MDG target for water would be met, but the target for sanitation missed considerably. The number of people without access to such services is still increasing in certain regions. Striking differences persist between urban and rural areas. Consideration of water quality and different classification of shared sanitation facilities would, however, alter estimates considerably. To achieve improved monitoring we propose: (1) considering the use of MLM as an alternative for estimating access to safe drinking-water and sanitation; (2) completing regular assessments of water quality and supporting the development of national regulatory frameworks as part of capacity development; (3) evaluating health impacts of shared sanitation; (4) using a more equitable presentation of countries' performances in providing improved services.

Key words | indicator, Millennium Development Goals, modeling, monitoring, sanitation, water

Jennyfer Wolf (corresponding author)

Sophie Bonjour

Annette Prüss-Ustün

Department for Public Health and Environment,
Evidence and Policy on Environmental Health,
World Health Organization,
20 Avenue Appia, CH-1211,
Geneva 27,
Switzerland
E-mail: wolfj@who.int

INTRODUCTION

Providing universal access to safe water and sanitation services could have prevented 1.9 million deaths and reduced global child mortality by 15% in 2004 (WHO 2009). Access to safe water and improved sanitation significantly reduces diarrheal diseases (Waddington *et al.* 2009; Cairncross *et al.* 2010) and other illnesses such as intestinal helminth infections, schistosomiasis and trachoma (Esrey *et al.* 1990; Ziegelbauer *et al.* 2012). One Millennium Development Goal (MDG) target is to halve, by 2015, the proportion of people without sustainable access to safe water and basic sanitation (United Nations 2012). However, in 2010 an estimated 2.5 billion people still lacked access to improved sanitation and 780 million to an improved water source (JMP 2012a). The term 'water' throughout this document refers to water for drinking, cooking and personal hygiene.

For future priority setting, we need reliable, reproducible, statistically sound estimates for country, regional and global access to safe water and sanitation. Since 1990, the World Health Organization (WHO)/United Nations Children's Fund (UNICEF) Joint Monitoring Programme (JMP) examines progress and trends in this connection (JMP 2010a). With the end of the MDG period approaching and the agenda for the post-MDG era under consideration, it is important to consider refinements of monitoring and evaluation. Current approaches are mostly limited to linear trends (JMP 2012a). Additionally, there has been debate whether estimates could be improved by considering water quality (Bain *et al.* 2012; JMP 2012a; Onda *et al.* 2012) and on the possible reclassification of certain sanitation services (JMP 2010a). Therefore we developed estimates for access to

improved water sources and improved sanitation facilities using advanced modeling methods and reconsidered the definition of the access indicators depending on safety for health. The JMP task force on methods recommended that the JMP method be reviewed (JMP 2010b). The content of this paper may contribute to these discussions.

This article presents trends in access to safe water and sanitation over 25 years using available survey information and a sound modeling approach. Furthermore, we discuss the inclusion of water quality, different ways to consider shared sanitation and the potential impact such changes would have. Finally, we propose an alternative indicator to monitor the MDG targets which would more equitably represent the performance of countries.

METHODS

Data compilation and classification

We used the JMP database on access to improved water sources and improved sanitation facilities. It contains datasets collected through nationally representative household surveys and censuses (JMP 2010a). The data represent percentages of households using different improved sources/facilities, disaggregated by urban and rural population. For the national level (urban and rural combined), nearly 1,100 data points for both water and sanitation were included. Detailed information about data sources and classification of a facility as improved or unimproved can be found in the JMP reports (JMP 2010a, 2012a). The survey estimates from the JMP datasets can be found on the JMP website ([www.wssinfo.org/documents-links/documents/?tx_displaycontroller\[type\]=country_files](http://www.wssinfo.org/documents-links/documents/?tx_displaycontroller[type]=country_files)). The number of surveys available ranged between zero and 30 with a mean of six per country. Out of 145 low and middle income countries (LMIC), 140 (for water) and 132 (for sanitation) are covered by at least one survey. A table with number of observations by time period and region is available in the Supplemental Material at www.who.int/quantifying_ehimpacts/en/index.html.

Prior to considering a dataset for estimation, the JMP examines every response category of the relevant questions of every survey to ensure they match those used for

reporting purposes. In cases of discrepancies with national figures, usually attributable to the categories used, JMP engages with the national monitoring authorities to identify problems and seek solutions. To date, JMP have had such discussions in over 40 countries. Most of the discrepancies arise from differences in definitions of improved access, especially in the older datasets. One example consists in an ‘uncovered’ latrine type in China which was classified as ‘unimproved’, but which would fall under the ‘improved’ JMP classification – the seat was indeed uncovered, but the pit itself – which matters for the JMP definition – was actually covered. Recent discussions with Chinese survey authorities revealed the reasons for these differences. Adjustments not only changed Chinese sanitation coverage but had a significant impact on global figures.

In general, JMP harmonization exercises led to internationally adopted and harmonized core questions and response categories and hence to greater data comparability and accuracy of estimates. Additionally, recent surveys provide more disaggregation, and therefore less ambiguity. Several initiatives are contributing to the ‘reconciliation’ between past and recent datasets, such as the Accelerated Data Programme of the International Household Survey Network, which was established to improve the coordination and effectiveness of surveys (International Household Survey Network 2012). However, harmonization between historical and recent data remains a challenge and not always completely achievable.

Modeling approach

Criteria for model selection included: (a) closeness of modeled estimates to the survey points without following all within-country variability which might be partly due to systematic and non-systematic error; (b) transparency, simplicity and reproducibility of the model; and (c) ability to estimate for countries with little or no information. We therefore applied a linear two-level model with a logit-transformation of the dependent variable (access to improved water sources or improved sanitation), a cubic spline transformation of the main predictor (time), region (21-Global Burden of Disease (GBD)-Regions (Harvard University *et al.* 2009)) as a covariate and a random intercept and slope by country.

Multilevel modeling (MLM) creates continuous estimates over the specified time period. It considers the hierarchical structure of the whole dataset: survey points are correlated within countries which are assumed to be a random sample from a bigger population. Instead of calculating an intercept and regression slope separately for each country as is currently done in JMP, the multilevel model estimates an average intercept and an average slope with residual variances across countries. In practice, countries are assumed to follow the regional mean in case the trend information for the country is scarce or absent. When there is reliable information for a specific country (i.e. many data points and little within-country variability) the country curve will closely follow the country survey points, whereas for unreliable information (i.e. few country data points or high within-country variability) the estimates will still be close to the survey points but the trend will tend to follow the overall mean (Goldstein 2010; Hox 2010; Steele 2011).

We applied a two-level model allowing a random intercept and slope by country. The model was applied separately to the total, the rural and the urban population. Estimates were derived using maximum likelihood. The dependent variable was logit-transformed to restrict estimates and confidence intervals between zero and one (or 100%) and to use the specific shape of the logit curve with a slower increase when access approaches 100%. The logit transformation leads to increasingly asymmetric and narrow confidence intervals close to zero or 100% (De Onis *et al.* 2004). Likelihood ratio test and the Akaike Information Criterion (AIC) were used to decide the inclusion of random and fixed effects. We assumed unstructured covariance between the random intercept and random slope. Random effects and the dependent variable (after transformation) followed normal distributions (Quené & van den Bergh 2004). A cubic spline transformation of time (the main predictor) was chosen on inspection of the curves and to accommodate additional flexibility for future trends (see additional explanations in the Supplemental Material at www.who.int/quantifying_ehimpacts/en/index.html). Knots, which determine the flexibility of the curve, were set after 25, 50 and 75% of data points. Sensitivity analyses were performed with different transformations of the dependent and independent variable (different splines and random/fixed effects, non-logit transformation) and the choice of the

final model was based on likelihood ratio tests, the AIC and inspection of the curves. For countries with no information, the regional mean trend was taken as the best estimate.

Confidence intervals on the national level were calculated as the square root of the combined fixed- and random-level variances, which were assumed to be independent. The regional estimates in Tables 1–3 were calculated as the population weighted average of the country estimates. The global estimate was calculated accordingly as the population weighted average of the regional estimates. Confidence intervals for regional and global estimates were calculated using regional and global standard errors derived as the square root of the weighted country variances. The country variances on the natural scale were estimated from the country logit variances using the delta method, which has been applied before and described in detail by De Onis *et al.* (2004). To calculate population numbers we used the population figures from the United Nations Population Division (2012).

We present estimates for WHO regions (Sub-Saharan Africa, the Americas, Eastern Mediterranean, Europe, South-East Asia, and Western Pacific – with high income countries (HIC) grouped separately (WHO 2012)) and, furthermore, disaggregated in urban and rural areas (Tables 1 and 2). For all analyses discussed in this paper, Equatorial Guinea was not considered a high income country but grouped with other Sub-Saharan African countries. All analyses were performed with Stata 12 (StataCorp. 2011. Stata Statistical Software: Release 12. College Station, TX: StataCorp. LP).

Water quality

Not all water sources that are classified as improved provide water with a quality that complies with WHO drinking water quality guidelines (WHO 2011) or are safe for health. Hence, the currently used MDG estimates should be corrected for access to safe water. Between 2004 and 2007, the JMP conducted nationally representative and comparable water quality tests in five pilot countries, the WHO/UNICEF Rapid Assessments of Drinking Water Quality (RADWQ) (JMP 2012b). These assessments covered Ethiopia, Jordan, Nicaragua, Nigeria, and Tajikistan, and tested water quality of different technologies for microbial and

Table 1 | Percentage of population without access to improved water sources, by region

Region ^a		1990		2010		2015	
		%	95% CI	%	95% CI	%	95% CI
<i>Low and middle income countries</i>							
Sub-Saharan Africa	Total	51.9	46.0, 57.8	35.9	29.7, 42.1	32.2	25.4, 39.0
	Urban	16.7		14.5		14.4	
	Rural	65.9		49.8		45.9	
Americas	Total	14.4	6.0, 22.8	5.8	2.8, 8.8	4.7	2.3, 7.1
	Urban	5.3		2.5		2.1	
	Rural	36.9		18.7		15.8	
Eastern Mediterranean	Total	21.5	14.7, 28.3	15.0	10.4, 19.6	13.7	9.0, 18.4
	Urban	7.4		6.2		6.3	
	Rural	31.4		22.1		20.1	
Europe	Total	10.5	6.2, 14.8	4.4	2.5, 6.3	3.6	1.9, 5.3
	Urban	2.9		1.1		0.9	
	Rural	22.5		9.9		8.4	
South-East Asia	Total	26.0	7.2, 44.8	11.9	2.2, 21.6	9.8	1.6, 18.0
	Urban	9.3		5.4		4.8	
	Rural	32.4		14.5		12.0	
Western Pacific	Total	32.7	0.1, 78.6	9.5	1.6, 40.9	6.8	1.1, 32.3
	Urban	4.1		1.7		1.4	
	Rural	44.4		16.8		12.9	
<i>High income countries</i>							
World	Total	1.3	0.4, 4.1	0.5	0.2, 1.4	0.4	0.1, 1.2
	Urban	0.4		0.1		0.1	
	Rural	4.3		1.4		1.1	
World	Total	23.3	11.2, 35.4	11.8	7.2, 16.4	10.1	6.5, 13.7
	Urban	4.9		3.5		3.4	
	Rural	37.3		20.1		17.7	

^aGrouped according to WHO regions and income category (WHO 2012).

chemical contamination for one point in time. Thermo-tolerant coliform bacteria were indicators for microbial contamination; fluoride, arsenic and nitrate were indicators for chemical contamination.

We also used similar assessments performed in China and India. In the Chinese assessment 1,604 and in the Indian 11,757 water sources were tested. Chinese RADWQ, however, covered one region only and tested total rather than thermotolerant coliforms. The Indian assessment was not conducted as an official RADWQ but followed the same methodology. It examined compliance to BIS 10500 (Bureau of Indian Standards 2005), which is based on WHO and national guidelines on drinking water quality. We only used the value for microbial water quality from the Indian RADWQ as chemical water quality testing was not done for arsenic. A systematic literature search in Medline and the internet did not yield any additional

significant country representative data on water quality at point of use for low income countries. The total information on water quality, therefore, does not exceed one or two country representative surveys per large geographical region.

We compiled water quality estimates for piped to the household and non-piped improved sources from the above described assessments. We then extrapolated these water quality estimates from the respective countries to other countries in the same region (WHO region). We estimated piped water using MLM (see Supplemental material for details, available online at <http://www.iwaponline.com/jwh/011/107.pdf>) and non-piped improved sources as the difference between total improved and piped sources by country. We then multiplied the respective water quality proportions with those national estimates on piped and non-piped sources to estimate the population proportion without access to safe water in 2010. Water quality from unimproved

Table 2 | Percentage of population without access to improved sanitation, by region

Region ^a		1990		2010		2015	
		%	95% CI	%	95% CI	%	95% CI
<i>Low and middle income countries</i>							
Sub-Saharan Africa	Total	73.3	69.3, 77.3	66.1	61.6, 70.7	64.0	57.2, 70.8
	Urban	56.6		54.9		55.1	
	Rural	80.4		74.2		70.8	
Americas	Total	32.6	16.3, 48.9	21.1	8.9, 33.3	19.3	7.9, 30.7
	Urban	20.7		15.8		15.2	
	Rural	62.4		41.0		36.6	
Eastern Mediterranean	Total	51.3	42.0, 60.6	35.4	24.8, 46.0	32.9	22.0, 43.8
	Urban	23.1		18.1		18.0	
	Rural	70.3		49.6		44.7	
Europe	Total	19.5	10.8, 28.2	16.6	8.2, 25.0	16.4	7.4, 25.4
	Urban	13.5		13.0		13.1	
	Rural	31.0		22.4		21.1	
South-East Asia	Total	74.8	62.0, 87.6	56.2	35.7, 76.7	51.7	29.7, 73.7
	Urban	48.6		35.8		33.7	
	Rural	84.5		66.1		59.8	
Western Pacific	Total	67.4	28.9, 91.3	34.1	7.8, 76.0	27.1	5.6, 70.0
	Urban	45.2		24.6		20.7	
	Rural	76.9		41.8		33.3	
<i>High income countries</i>							
World	Total	1.5	0.7, 3.0	0.6	0.3, 1.3	0.5	0.2, 1.2
	Urban	0.5		0.2		0.2	
	Rural	3.5		1.4		1.2	
World	Total	50.4	40.8, 60.0	36.5	25.6, 47.4	33.6	23.4, 43.8
	Urban	24.5		20.8		20.2	
	Rural	70.1		52.4		47.6	

^aGrouped according to WHO regions and income category (WHO 2012).

sources was considered as 100% contaminated and water sources in HIC were assumed to be 100% safe.

Shared sanitation

Sanitation shared between households and public sanitation are on the increase in developing countries, but the boundaries between the two remain nebulous. Generally, shared facilities use improved technology. However, the JMP considers every shared sanitation technology as unimproved, given uncertainty about actual use, hygiene and safety for health.

The JMP adjusts for shared sanitation in its final estimates for access to improved sanitation by subtracting the

mean over available survey estimates for shared sanitation use individually by country. However, this approach is currently not homogeneous, as for 34 LMIC no data on shared sanitation use are available, in which case no value will be subtracted. Therefore, JMP final estimates cannot be compared across countries, as the final value for access to improved sanitation sometimes includes and sometimes excludes shared sanitation facilities.

For our final estimates (as presented in Tables 1–3) we continued using the JMP classification and considered all shared sanitation as unimproved. We estimated shared sanitation use with a two level MLM for LMIC (see Supplemental material for additional information, available online at <http://www.iwaponline.com/jwh/011/107.pdf>).

Table 3 | Total population without access to improved water sources or improved sanitation, by region

Region ^a		1990 n (in million)	2010 n (in million)	2015 n (in million)
<i>Low and middle income countries</i>				
Sub-Saharan Africa	Water	263	300	304
	Sanitation	371	553	604
Americas	Water	63	34	29
	Sanitation	142	123	119
Eastern Mediterranean	Water	77	83	82
	Sanitation	183	194	198
Europe	Water	41	18	15
	Sanitation	77	67	67
South-East Asia	Water	343	215	187
	Sanitation	985	1,017	994
Western Pacific	Water	430	151	111
	Sanitation	886	540	442
<i>High income countries</i>				
World	Water	1,229	806	733
	Sanitation	2,658	2,501	2,429

^aGrouped according to WHO regions and income category (WHO 2012).

For shared sanitation use, only 192 country, 229 rural and 233 urban survey estimates were available. The regional mean was taken for LMIC with no information. For HIC, the proportion of shared sanitation use was assumed to be zero unless survey estimates were available for those countries, in which case their mean was extrapolated to the whole time period. Such estimated values for shared sanitation use were then deducted from the original survey points which indicate the use of improved shared and unshared facilities. The multilevel model was run on these estimates (survey points minus estimates for shared sanitation). For comparison, we subsequently recalculated global figures while considering shared sanitation of an improved technology as improved.

RESULTS

The complete time series (1990–2015) for each country is available at www.who.int/quantifying_ehimpacts/en/index.html. This site also contains additional information (number

of surveys per time period and region, model equations, model evaluation, etc.) under ‘Supplemental material’.

Country, regional and global trends

Complete data series between 1990 and 2015 for access to improved water sources and sanitation were generated for 193 WHO Member States. We estimate that, globally, the proportion of people without access to an improved water source will be reduced from 23% in 1990 to 10% in 2015. The number of unserved people, however, will be reduced by only 40%. Sub-Saharan Africa and the Eastern Mediterranean region will not halve their proportion of the unserved population. Furthermore, the number of people without access to an improved water source in these two regions is projected to increase by an additional 46 million people (Tables 1 and 3).

The global proportion of people without access to improved sanitation will be reduced from 50% in 1990 to 34% in 2015. The number of unserved people will decline only by little more than 200 million. If we were to apply the MDG target to regions, only Western Pacific would achieve the sanitation target by 2015 (Tables 2 and 3).

Figures 1 and 2 show the modeled global and regional trend in access to improved water sources and sanitation facilities between 1990 and 2015. The diamonds on the

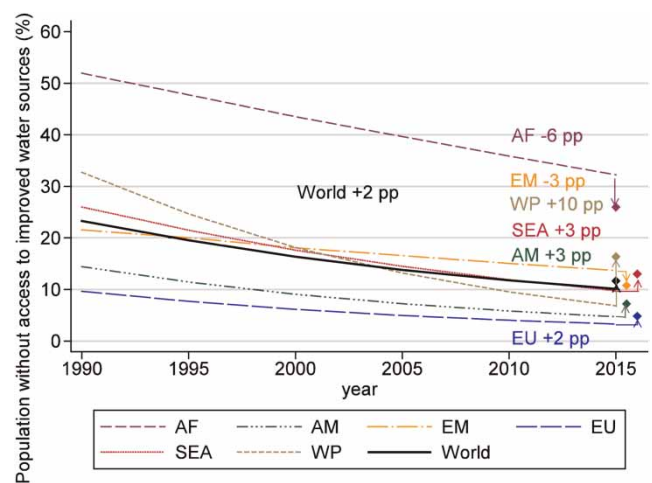


Figure 1 | Regional and global development towards the MDG water target. pp: percentage points, AF: Sub-Saharan Africa, AM: Americas, EM: Eastern Mediterranean, EU: Europe, SEA: South-East Asia, WP: Western Pacific, low and middle income countries only, world line includes high income countries. Diamond: MDG-target (if extrapolated to regions), numbers (pp): distance from MDG-target.

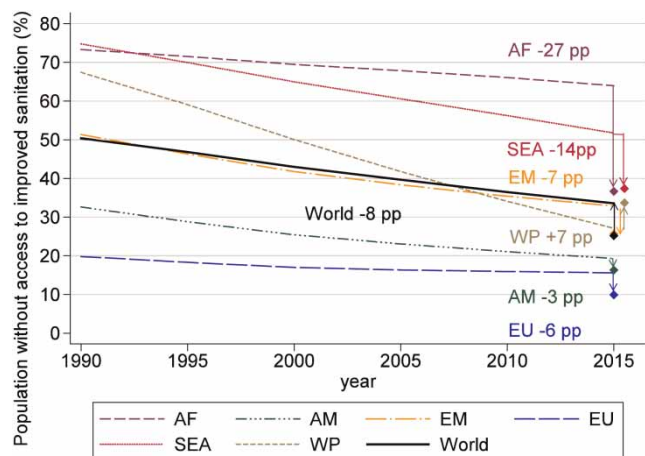


Figure 2 | Regional and global development towards the MDG sanitation target. pp: percentage points, AF: Sub-Saharan Africa, AM: Americas, EM: Eastern Mediterranean, EU: Europe, SEA: South-East Asia, WP: Western Pacific, low and middle income countries only, world line includes high income countries. Diamond: MDG-target (if extrapolated to regions), numbers (pp): distance from MDG-target.

right of the figure represent the MDG target globally and extrapolated to the region. The percentage points in the two figures indicate the difference between the MDG and the actual achievement; a minus indicates an estimated lagging behind the goal. Sub-Saharan Africa, for example, is estimated to miss the target of halving its population without access to improved water sources in 2015 by around six percentage points.

Access to services is consistently higher for urban compared to rural areas. However, the decrease in the proportion of the urban population without access to improved services between 1990 and 2015 was slower compared to the rural population (Tables 1 and 2). The total number of the urban population without access will rise globally between 1990 and 2015 from 109 to 130 million (access to an improved water source) and from 548 million (access to improved sanitation).

Taking water quality into account

After adjusting our estimates with summary microbial and overall water quality (Table 4), calculated as described above, the proportion of the world's population without access to safe water in 2015 rose from 12 to 30% for microbiologically unsafe water and to 33% for overall unsafe water (Table 5).

Table 4 | Assumed regional microbial and overall compliance percentages (LMIC only)

Region ^a	Microbial compliance ^b		Overall compliance ^c	
	Piped (%)	Other improved (%)	Piped (%)	Other improved (%)
Sub-Saharan Africa	83.1	67.2	78.9	63.2
Americas	89.9	34.0	89.0 ^d	28.6 ^d
Eastern Mediterranean	99.9	100 ^e	97.8	100 ^e
Europe	88.6	82.0	88.2	82.0
South-East Asia ^f	43.0	56.7	43.0 ^e	56.7 ^e
Western Pacific	99.0	53.7	98.0 ^d	24.2 ^d

^aGrouped according to WHO regions (WHO 2012).

^bIndicator: thermotolerant *Escherichia coli* (China: total coliforms).

^cIndicators: thermotolerant *E. coli* (China: total coliforms), arsenic, nitrate, fluoride.

^dOverall compliance not recorded, calculated assuming independence of individual estimates.

^eChemical compliance did not include arsenic and therefore overall compliance was not calculated.

^fCompliance to BIS 10500 (Bureau of Indian Standards 2005).

Differing classifications of shared sanitation

Our final estimates on access to improved sanitation in Tables 2 and 3 and Figure 2 do not include shared facilities because we classified all shared sanitation as unimproved and deducted modeled estimates of shared sanitation use for each country from the original survey points. However, because of the ongoing controversy about the actual impact on health of shared facilities (see also Discussion section) we recalculated our estimates to show the approximate impact on results a different classification of shared sanitation might have. When all shared sanitation facilities of an improved technology were classified as 'improved', only 23% of the world population would be without access in 2015 compared to 34% with the current classification. Furthermore, the proportion of the population without access to improved sanitation would nearly halve between 1990 and 2015 (Table 6).

DISCUSSION

Results

The MDG drinking-water target has been met if access to improved water sources is equated with sustainable access

Table 5 | Estimates for not having access to safe water in 2010 adjusted for water quality

Region ^a	Population unserved ^b	Population unserved adjusted microbial compliance ^c		Population unserved adjusted overall compliance ^d	
	%	N in million	%	N in million	%
<i>Low and middle income countries</i>					
Sub-Saharan Africa	35.9	453	54.1	475	56.7
Americas	5.8	119	20.5	127	21.8 ^e
Eastern Mediterranean	15.0	83	15.1 ^f	90	16.3 ^f
Europe	4.4	67	16.5	68	16.8
South-East Asia ^g	11.9	960	53.1	960 ^h	53.1 ^h
Western Pacific	9.5	374	23.6	520	32.8 ^e
<i>High income countries</i>	0.5	5	0.5	5	0.5
World	11.8	2,062	30.1	2,244	32.7

^aGrouped according to WHO regions and income category (WHO 2012).

^bWithout access to an improved water source.

^cAdjusted for microbial quality.

^dAdjusted for microbial and chemical quality.

^eOverall compliance not recorded, calculated assuming independence of individual estimates.

^fOnly piped water was adjusted.

^gCompliance to BIS 10500 (Bureau of Indian Standards 2005).

^hInformation available for microbial compliance only.

Table 6 | Global estimates when shared sanitation of an improved technology is classified as 'unimproved' versus 'improved'

Sanitation	MLM ^a main estimates		MLM ^a estimate, recalculation	
	Shared sanitation as 'unimproved' N in million	(%)	Shared sanitation as 'improved' N in million	(%)
Population not served 1990	2,658	(50.4)	2,402	(45.6)
Population not served 2010	2,501	(36.5)	1,821	(26.6)
Population not served 2015	2,429	(33.6)	1,656	(22.9)

^aMLM: multilevel modeling.

to 'safe' water. We estimate that in 2015 only 10% of the world population will not have access to an improved water source. However, the sanitation target will be missed substantially if current trends continue. Alarming, the number of people without access to an improved water source or improved sanitation increased over time in some regions. This shows that the rates of improvement in access are generally not keeping up with population growth, especially in urban areas.

Generally, urban populations are considerably better served. Urbanization can facilitate the provision and lower the costs of facilities (Satterthwaite 2008). However, the comparatively small progress in those areas indicates that

service provision is increasingly lagging behind population growth and rapid urbanization (JMP 2012a).

Modeling approach

We believe that MLM offers several advantages over traditional linear regression used by the JMP. Those include a single model for all countries, a flexible, still more stable curve, a continuous time series for all countries covering the whole MDG period, the additional information for countries with scarce data and the possibility to estimate for countries with no information. The JMP currently extrapolates the regression line over a limited number of

years after the latest point and subsequently extends it horizontally (JMP 2012c). This leads to a sudden step in the estimates which is unlikely to happen in reality (Figures 3 and 4). Although global estimates of MLM differ only slightly from JMP estimates, they can differ substantially

for individual countries, with up to 14 percentage points for access to an improved water source and 49 percentage points for access to improved sanitation. Furthermore, MLM proposes approximate estimates based on the regional mean for nine countries for water and 21 countries for

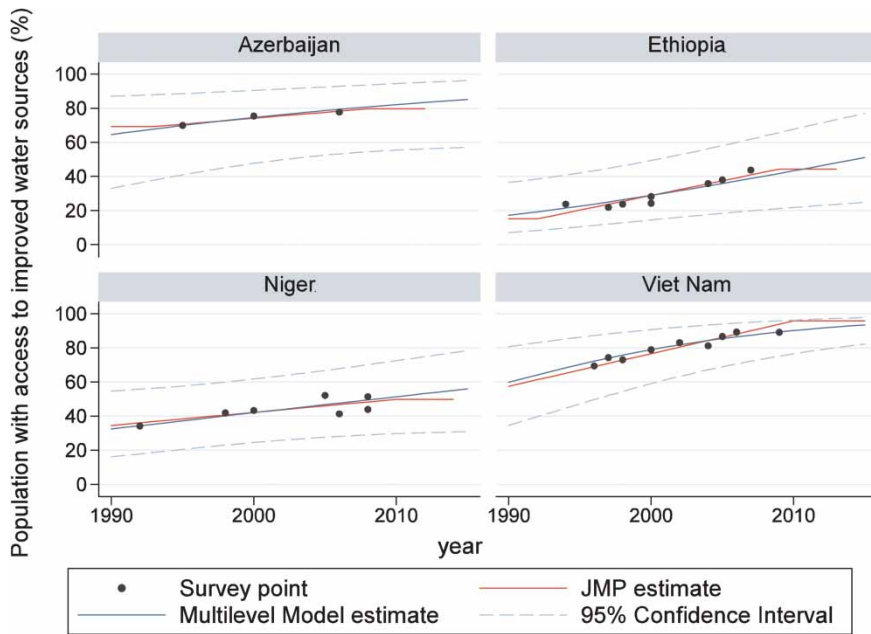


Figure 3 | Modeled access to an improved water source using multilevel modeling and JMP-methodology and survey data, country examples. JMP: Joint Monitoring Programme.

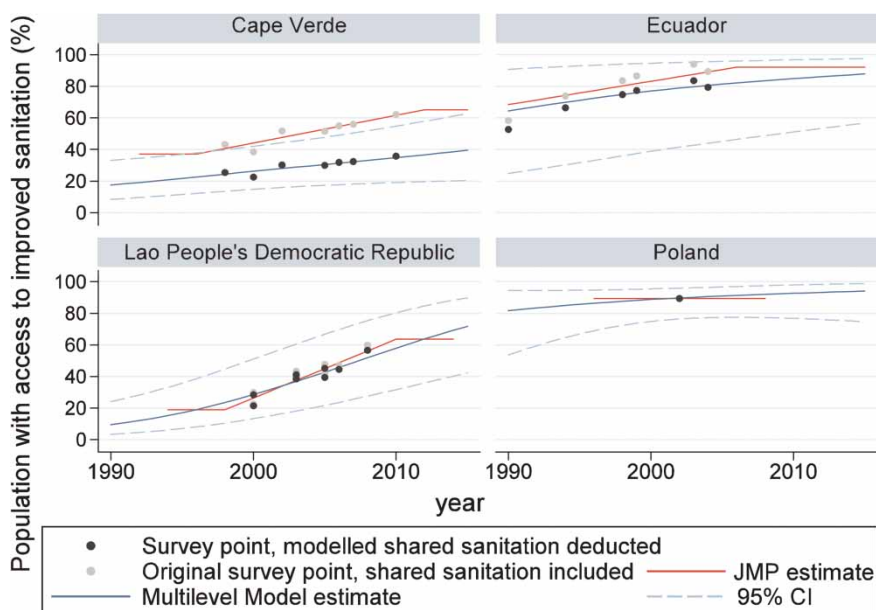


Figure 4 | Modeled access to improved sanitation using multilevel modeling and JMP-methodology, and survey data, country examples. JMP: Joint Monitoring Programme.

sanitation when no data are available. These estimates for countries without suitable survey data are indicative values only, to be used mainly for computing regional and global estimates, and are not meant to replace the more accurate measurements made by surveys or census. Current JMP method excludes countries without any survey point for computing regional or global estimates.

Some limitations should be noted. For countries with limited data, more information is used from other countries compared to countries with more information. We did not include further covariates into the model because they did not improve the model. In addition, forecasts to 2015 are based on current trends, meaning that policy or economic changes initiated after the last survey are not reflected. We also did not consider uncertainties associated with the survey estimates arising from sampling and non-sampling errors.

Consideration of water quality in monitoring the MDG targets

The MDG target addresses access to 'safe' water and 'basic' sanitation, whereas the indicators to monitor the targets are use of an 'improved' source or facility.

It was shown (JMP 2011; Bain *et al.* 2012) that considering representative data on water quality from the RADWQ considerably changes estimates for access to 'safe' water. To estimate access to actually 'safe' water on our estimates, we extrapolated national data on water quality of those assessments to countries in the same region and to the year 2010. Thereby, the number of people without access to safe water tripled and the unserved proportion increased by 21 percentage points in 2010. The currently used proxy indicator therefore might considerably overestimate the true access to safe water. However, data obtained by the RADWQ have to be interpreted with caution as they present a one-time measurement, do not consider seasonal fluctuations of water quality and use data collection methods that are not fully harmonized across countries (JMP 2010c). China, for example, reported total coliforms as indicator for microbial water quality whereas the other RADWQ measure thermotolerant *E. coli*. India did not test for contamination with arsenic and therefore overall compliance was not reported for South-East Asia. Our

estimates are therefore not exact but highlight the difference between access to 'improved' services and actual safe access and the importance of collecting nationally representative water quality data by technology type.

If our estimates were adjusted for data on microbial compliance over the whole MDG period, they would show a shortfall towards the water target by around nine percentage points in 2015. This estimate, based on extrapolation of national data to the region, is remarkably close to a previous estimate based on modeling water quality using data from the five published RADWQ (Onda *et al.* 2012). In addition, our analysis includes field data for China and India, which together constitute about 37% of the world's population. This analysis therefore extends but also strengthens previous results. It should, however, be treated with caution because it is unlikely that compliance proportions remained constant over time and that country data can be extrapolated to other countries. More and better information on water quality would lead to more meaningful estimates.

Shared sanitation

'Shared sanitation' in the JMP dataset combines private sanitation shared between households, and public sanitation. Public sanitation was shown not to reduce morbidity in particular settings (Khan 1987). Additionally, it is often used by too many people, poorly maintained, far away, expensive and can pose a risk for interpersonal violence (Bapat & Agarwal 2003; World Bank 2006; Amnesty International 2010). This is likely to reduce its use and result in alternatives leading to contact with feces, like open defecation. Open defecation, even done by few people, has health impacts on the whole community by contaminating the environment and increasing the risk of infection (Saywell & Shaw 1999; Cairncross & Valdmanis 2006).

A bigger controversy exists around the health impacts of private facilities shared between households (Cairncross & Valdmanis 2006; Montgomery *et al.* 2010). Most of those facilities are used by few households and it was argued that a high proportion is probably safe for health (JMP 2010b). As limited resources and space, especially in densely populated urban areas, impedes the installation of one toilet per household (Saywell & Shaw 1999), this controversy deserves urgent clarification. We show in an exemplary

calculation that classifying shared, otherwise improved sanitation as improved would have a huge impact on global figures. However, a different classification of (some) shared facilities as improved should be based on solid evidence. As this is currently not available, and furthermore data on shared sanitation use do not allow disaggregation into public or private sanitation, we classified all shared sanitation as unimproved, as done by JMP.

Additionally to the above, our model projects a constant increase of shared sanitation use between 1990 and 2015 worldwide (from 13% to 17%, or 511 million additional people).

Additional measure for progress

Halving a high proportion without access is much harder compared to halving a low one. This measure is, however, used to monitor the MDG target at global level (JMP 2012a). Halving a high proportion at country level means that a country supplied large parts of its population with services during the defined period. Poor countries are often in the

difficult situation of both a high proportion without access and high population growth. They might have made remarkable progress in delivering services to many additional people, yet the percent reduction of the unserved proportion can be small. To acknowledge this, we show both the progress in reducing the proportion of the population without access ('MDG-type-progress', x -axis) and the progress in terms of the additional population served, meaning the total number of additional people served between 1990 and 2015 as a percentage of the 2015 population (y -axis) (Figures 5 and 6).

CONCLUSIONS

1. Multilevel modeling is transparent, flexible and easily reproducible, and offers several advantages over traditional linear regression. Those include continuous time series estimates for the whole MDG period for all countries even in the challenging but frequent situation of data scarcity.

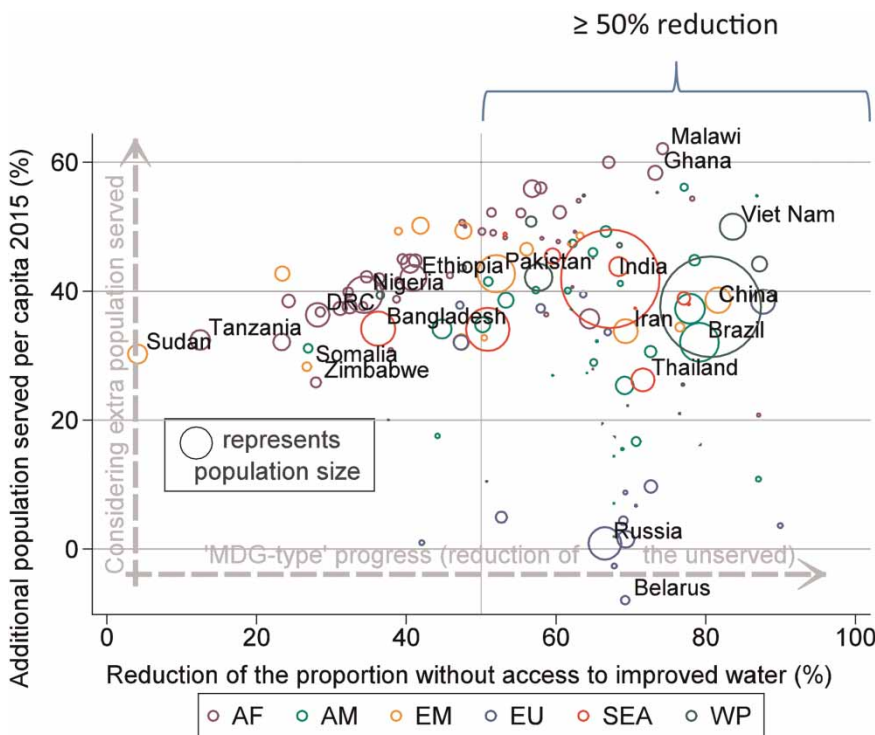


Figure 5 | Country progress on water: additional population served versus reduction of proportion of population unserved, between 1990 and 2015. AF: Sub-Saharan Africa, AM: Americas, EM: Eastern Mediterranean, EU: Europe, SEA: South-East Asia, WP: Western Pacific. Low and middle income countries only, scale does not cover all countries, $\geq 50\%$ reduction would correspond to global MDG target.

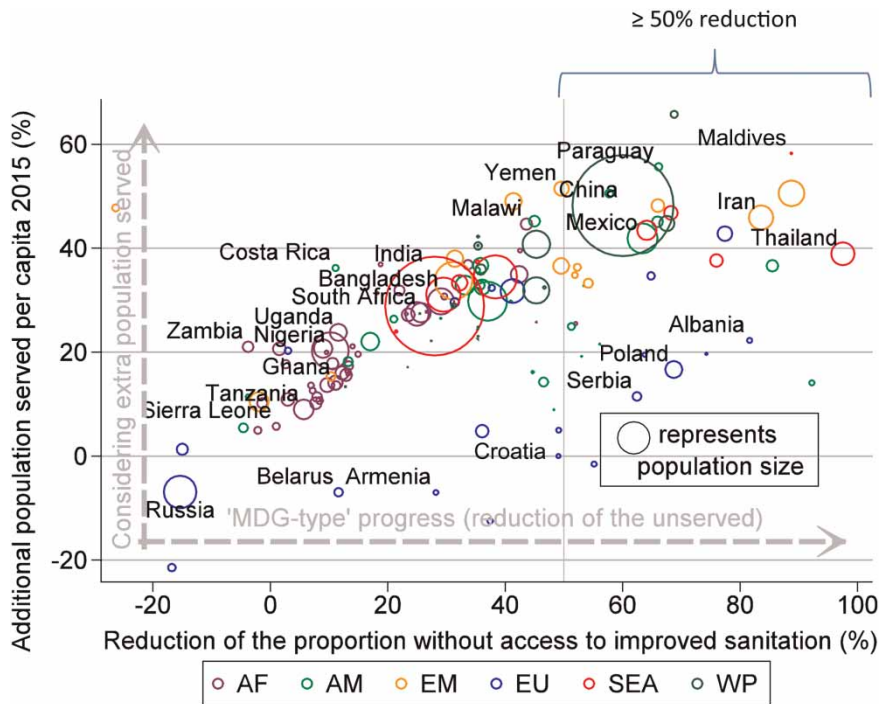


Figure 6 | Country progress on sanitation: additional population served versus reduction of proportion of population unserved, between 1990 and 2015. AF: Sub-Saharan Africa, AM: Americas, EM: Eastern Mediterranean, EU: Europe, SEA: South-East Asia, WP: Western Pacific. Low and middle income countries only, scale does not cover all countries, $\geq 50\%$ reduction would correspond to global MDG target.

- The MDG target for water, as measured by the indicator of access to improved drinking-water sources, will be achieved by 2015. The MDG target for sanitation is unlikely to be achieved. In some regions the number of people without access to services is rising, indicating that population growth and rapid urbanization have started to outpace new service provision.
- Correction of the currently used MDG indicator for 'access to safe drinking-water' with information on water quality would provide a better account of the safety for health. Based on our approximation, it is unclear whether the MDG water target would actually be achieved by 2015, as representative data are currently available for only few developing countries and for one point in time. To regularly conduct national assessments of water quality is important and should be implemented after careful consideration of cost-effectiveness, sample location, timing and indicators.
- At the moment the evidence is too scarce to clarify the ambiguity around the health impacts of shared sanitation. Changing the classification from shared facilities of an

- improved technology from unimproved to improved would have a huge impact not only on estimates but also on resource allocation and program planning, and should therefore be based only on solid evidence. We need more information on the proportion of shared sanitation, but also on the condition of those facilities and whether they are private or public. Furthermore, we do not have sufficient epidemiological evidence on the association between sharing sanitation facilities and morbidity.
- Monitoring the reduction of the unserved proportion alone does not provide the full picture regarding progress made. Considering also the population that gained access during the relevant time period adds substantial information on actual efforts made by a country.

ACKNOWLEDGEMENT

We thank Abdou-Salam Savadogo for his valuable contribution to our work.

DISCLAIMER

The authors are staff members of the World Health Organization. The authors alone are responsible for the views expressed in this publication and they do not necessarily represent the decisions or policies of the World Health Organization.

REFERENCES

- Amnesty International 2010 *Kenya: Insecurity and Indignity: Women's Experiences in the Slums of Nairobi, Kenya*. Amnesty International Publications, London, UK.
- Bain, R., Gundry, S., Wright, J., Yang, H., Pedley, S. & Bartram, J. 2012 Accounting for water quality in monitoring access to safe drinking-water as part of the Millennium Development Goals: lessons from five countries. *Bull. World Health Org.* **90** (3), 228–235.
- Bapat, M. & Agarwal, I. 2003 Our needs, our priorities; women and men from the slums in Mumbai and Pune talk about their needs for water and sanitation. *Environ. Urban.* **15** (2), 71–86.
- Bureau of Indian Standards 2005 Indian Standard, Drinking Water Specification, Second Revision (No. 13.060.20). New Delhi.
- Cairncross, S. & Valdmanis, V. 2006 Water supply, sanitation, and hygiene promotion. In: Jamison, D. T., Breman, J. G., Measham, A. R., Alleyne, G., Claeson, M., Evans, D. B., Jha, P., Mills, A. & Musgrove, P., editors. *Disease Control Priorities in Developing Countries*. Oxford University Press, Washington, pp. 771–792.
- Cairncross, S., Hunt, C., Boisson, S., Bostoen, K., Curtis, V., Fung, I. C. H. & Schmidt, W. P. 2010 Water, sanitation and hygiene for the prevention of diarrhoea. *Int. J. Epidemiol.* **39** (suppl. 1), i193–i205.
- De Onis, M., Blössner, M., Borghi, E., Morris, R. & Frongillo, E. A. 2004 Methodology for estimating regional and global trends of child malnutrition. *Int. J. Epidemiol.* **33** (6), 1260–1270.
- Esrey, S. A., Potash, J. B., Roberts, L. & Shiff, C. 1990 Health Benefits from Improvements in Water Supply and Sanitation: Survey and Analysis of the Literature on Selected Diseases (WASH Technical Report No. 66). Environmental Health Project, USAID, Washington.
- Goldstein, H. 2010 *Multilevel Statistical Models*, 4th edn. Wiley, UK.
- Harvard University, Institute for Health Metrics and Evaluation, John Hopkins University, University of Queensland, World Health Organization 2009 Chapter 8: Analysis and Presentation of Regions. In: *GBD Study Operations Manual*, Final Draft.
- Hox, J. 2010 *Multilevel Analysis, Techniques and Applications, 2nd edn. Quantitative Methodology Series*. Routledge, New York.
- International Household Survey Network 2012 Accelerated Data Program. Available from: www.ihsn.org/adp/.
- JMP 2010a *Progress on Sanitation and Drinking Water, 2010 Update*. UNICEF, World Health Organization, Geneva, Switzerland.
- JMP 2010b JMP Sanitation and Method Task Force Meeting Report (Technical Task Force Meeting). New York.
- JMP 2010c JMP Monitoring Drinking-water Quality Task Force Meeting Report (Technical Task Force Meeting). France.
- JMP 2011 *Drinking Water: Equity, Safety and Sustainability, JMP Thematic Report in Drinking Water*. UNICEF, World Health Organization.
- JMP 2012a *Progress on Drinking Water and Sanitation: 2012 Update*. UNICEF, World Health Organization.
- JMP 2012b JMP > Welcome to the WHO & UNICEF Joint Monitoring Programme: documents. Available from: [www.wssinfo.org/documents-links/documents/?tx_displaycontroller\[type\]=water_quality_reports](http://www.wssinfo.org/documents-links/documents/?tx_displaycontroller[type]=water_quality_reports).
- JMP 2012c JMP > Welcome to the WHO & UNICEF Joint Monitoring Programme: method. Available from: www.wssinfo.org/definitions-methods/method/.
- Khan, M. U. 1987 Limitation of communal latrines in changing the prevalence of parasites and diarrhoeal attack rate in Dhaka peri-urban slums. *Environ. Pollut.* **47** (3), 187–194.
- Montgomery, M. A., Desai, M. M. & Elimelech, M. 2010 Comparing the effectiveness of shared versus private latrines in preventing trachoma in rural Tanzania. *Am. J. Trop. Med. Hyg.* **82** (4), 693–695.
- Onda, K., LoBuglio, J. & Bartram, J. 2012 Global access to safe water: accounting for water quality and the resulting impact on MDG progress. *Int. J. Environ. Res. Public Health* **9** (3), 880–894.
- Quené, H. & van den Bergh, H. 2004 On multi-level modeling of data from repeated measures designs: a tutorial. *Speech Commun.* **43** (1–2), 103–121.
- Satterthwaite, D. 2008 Urbanization and sustainable development; Some notes for the presentation by David Satterthwaite for the UN Population Division.
- Saywell, D. & Shaw, R. 1999 *On-plot Sanitation in Urban Areas (Technical Brief No. 61)*. WELL, London.
- Steele, F. 2011 Module 5: Introduction to Multilevel Modelling Concepts. Available from: www.bristol.ac.uk/cmm/learning/course.html.
- United Nations 2012 United Nations Millennium Development Goals. Available from: www.un.org/millenniumgoals/envIRON.shtml
- United Nations Population Division 2012 United Nations Population Division Home Page. Available from: www.un.org/esa/population/.
- Waddington, H., Snilstveit, B., White, H. & Fewtrell, L. 2009 *Water, Sanitation and Hygiene Interventions to Combat Childhood Diarrhoea in Developing Countries*.

- International Initiative for Impact Evaluation,
New Delhi, India.
- WHO 2009 *Global Health Risks, Mortality and Burden of Disease Attributable to Selected Major Risks*. Geneva, Switzerland.
- WHO 2011 *Guidelines for Drinking-water Quality*, 4th edn.
Geneva, Switzerland.
- WHO 2012 *World Health Statistics 2012*. Geneva, Switzerland.
- World Bank 2006 *Kenya, Inside Informality: Poverty, Jobs, Housing and Services in Nairobi's Slums (No. 36347-KE)*.
Water and Urban Unit 1, Africa Region, World Bank.
- Ziegelbauer, K., Speich, B., Mäusezahl, D., Bos, R., Keiser, J. & Utzinger, J. 2012 [Effect of sanitation on soil-transmitted helminth infection: systematic review and meta-analysis](#). *PLoS Med.* **9** (1), e1001162.

First received 15 June 2012; accepted in revised form 12 November 2012. Available online 17 December 2012