PLOS WATER

RESEARCH ARTICLE

Every rung counts–A retrospective analysis of global sanitation progress across the service-level ladder under the MDGs

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OPEN ACCESS

Citation: Zimmerman J, Sheridan C, Cumming O, Elliott M (2022) Every rung counts–A retrospective analysis of global sanitation progress across the service-level ladder under the MDGs. PLOS Water 1(2): e0000002. https://doi.org/10.1371/journal.pwat.0000002

Editor: Eugene Appiah-Effah, Kwame Nkrumah University of Science and Technology, GHANA

Received: June 3, 2021

Accepted: November 2, 2021

Published: February 15, 2022

Data Availability Statement: All data used in the analysis are available for download at my public research website (MS Excel format): https://melliott.people.ua.edu/data.html.

Funding: The authors received no specific funding for this work.

Competing interests: The authors have declared that no competing interests exist

Abstract

The household sanitation target during the Millennium Development Goal (MDG) period used a binary "Improved"/"Unimproved" metric to evaluate progress. The "Unimproved" category was divided into three service levels: Shared Sanitation (facilities acceptable), Unimproved Facilities, and Open Defecation (no facility). Despite these data being publicly available, no analysis of country-level progress across these sanitation service levels during the MDGs has been published. We propose that retrospective analysis of progress across service levels can illuminate the diverse approaches used to address particular urban and rural sanitation deficits, and may provide insight to national and global actors in their ongoing efforts to address household sanitation. Additionally, we propose that a Sanitation Ladder Score, weighted to ascribe full, partial, and no credit to use of improved, shared and unimproved, and open defecation, respectively, is essential for concise communication of progress. Our analysis required gap-filling of data missing from the Joint Monitoring Programme (JMP) dataset; our final dataset consists of 190 countries representing 99.8% of global population. 149 countries achieved greater progress on the Sanitation Ladder Score than on the MDG metric. Using the four JMP progress categories, 144 countries fell into the same progress category and 41 achieved a higher category of Ladder Score progress. Countries with large gains in shared sanitation tended to have much greater progress on the Sanitation Ladder Score than on the MDG metric. A more detailed analysis is reported for six countries, with insight from the literature into their approaches. This Sanitation Ladder Score could be modified to incorporate the new "Safely Managed" service level tracked under the Sustainable Development Goals (SDGs) and likewise could be modified for other SDG targets for which multiple levels of service/achievement are reported. We encourage others to build upon our analysis; our complete dataset is freely available online (https://melliott.people.ua.edu/data.html).

Introduction

Sanitation has been defined in many ways of varying scope, but one key aspect of all definitions of sanitation is that it includes the safe management of human excreta. Sanitation is an essential foundation for public health [1, 2] and "the sanitary revolution" was identified by readers of the British Medical Journal as the most important medical advance since the journal was founded in 1840 [3]. Approximately 74% of the global population have access to household sanitation classified as either "safely managed" or "basic"; that is a flush toilet, hygienic pit latrines or similar technology; and nearly 9% (696 million people) have no sanitation at all, that is they practice open defecation (OD). The remaining portion of the global population use some form of shared sanitation facility or an unimproved or unhygienic facility [4].

The Millennium Development Goal (MDG) target for sanitation to "halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation" was established in 2004 but with 1990 as the baseline and 2015 as the endline [5]. Under the sanitation MDG target, sanitation was classified simply as either "improved" or "unimproved". While this simple pass-fail criterion had advantages in terms of simplicity and ease of communication, within a few years a number of shortcomings of this approach had been identified by the WaSH (water, sanitation and hygiene) community [6, 7].

One key concern with the MDG sanitation target was that a binary criterion may have reduced the priority given to other aspects of sanitation service-level that also bring important incremental gains in health and well-being [6, 8]. However, service-level improvements below the binary threshold (e.g., households moving from open defecation to a shared latrine) or above the threshold (e.g., providing a networked sewer connection to households formerly using pit latrines) were not counted as contributing to progress toward the MDGs. There was also some concern that the binary criterion would incentivize countries to focus on upgrading the service level of those with existing sanitation service so that it met the "improved" benchmark and neglect the most difficult cases in which it may be infeasible for each household to have its own improved sanitation facility (e.g., those practicing open defecation in informal settlements). Many studies have shown that preventing open defecation and providing other improvements in sanitation service yield health, cognitive and other benefits [9–12].

In summary, the lack of credit toward MDG targets for many improvements in sanitation service level was inconsistent with the broader goals of global development. During the MDG period, this concern led to calls for "ladder-based" approaches that would include credit for shared sanitation and eliminating open defecation [6] and in the lead-up to the 2016–2030 Sustainable Development Goals (SDGs), formulation of a ladder-based benchmarking process was a major concern [13–15]. Finally, service-level ladders were included in the SDGs, although a sanitation facility that would be defined as "Basic" sanitation if used by a single family was defined as "Limited" if shared between households. Despite the broad push for monitoring of different sanitation service levels under the SDGs, there are both substantial knowledge gaps in how countries progressed across the sanitation service-levels during the MDG period and a complexity to sanitation ladder monitoring under the SDGs that could benefit from further investigation.

While the potential benefits of a single, ladder-based sanitation score have been suggested [8], the extent to which countries made progress on the sanitation ladder during the MDG period has not been investigated. For example, it is unknown how much progress countries made on sanitation ladder from 1990–2015 and how ladder progress compared to progress using the binary MDG target. While ladder progress was not integrated into MDG targets, the Joint Monitoring Programme (JMP) took the initiative to monitor and report on sanitation

coverage across four service levels in both urban and rural areas of most countries. JMP's monitoring and reporting enables retrospective analysis of progress on the sanitation ladder.

In 2008, JMP began dividing the "Unimproved" category into three distinct service levels and subsequent reports included four sanitation service levels for countries with sufficient data: (1) Improved, (2) Shared Improved, (3) "Other Unimproved" and (4) Open Defecation [16]. Under the SDGs, these service levels are referred to as (1) Basic, (2) Limited, (3) Unimproved and (4) Open Defecation, respectively (the SDG gold standard category, "Safely Managed" sanitation, was not monitored by JMP during the MDG period). The "Shared improved"/"Limited" category includes facilities that would be considered improved were they not used by multiple households [16]; these were not counted toward MDG progress due to beliefs that they were more likely to be unhygienic and have limited accessibility [17, 18].

Monitoring and reporting of multiple sanitation service levels is essential, but changes across four-to-five service levels are not easy to summarize or communicate. Therefore, the global community needs a single metric to track country-level sanitation progress that both incorporates service levels across the sanitation ladder and can be quantified in a single, easily communicated score. Although others have proposed the use of a single score to assess sanitation across service levels [8, 19], a more detailed retrospective analysis of sanitation ladder progress over the MDG period is lacking in the literature. Additionally, a retrospective evaluation of country-level ladder progress relative to MDG progress is needed because the binary MDG metric fails to provide insight into the various approaches that enabled progress across the sanitation ladder.

Our Objectives in this paper are to: (1) describe the Sanitation Ladder Score metric, (2) gap-fill global data to enable application of the Sanitation Ladder Score to country-level progress across the sanitation service levels during the 1990–2015 MDG period and (3) compare global and country-level progress between the binary MDG sanitation target and the Sanitation Ladder Score from 1990–2015. Examination of progress across sanitation service levels in both urban and rural areas of particular countries will yield illustrative examples of the diverse profiles of progress across the sanitation ladder that may have been concealed by the binary MDG target. The complete gap-filled dataset is available in MS Excel format at https://melliott.people.ua.edu/data.html.

The possible adverse effects of global benchmarks for national performance, including perverse incentives and unintended consequences, have been described across a broad range of development-related targets [20–22]. This article presents a detailed, country-by-country, retrospective analysis of global progress toward a specific development goal (sanitation access) for which the high-profile global target (MDG 7 Target 10b) allocated credit for some but not all forms of progress.

Methods

Data

This analysis uses country level data made available by the World Health Organization (WHO) and United Nations Children's Fund (UNICEF) JMP to assess national and global progress towards the sanitation MDG target [23]; data were downloaded from the JMP website following publication of the final 2015 sanitation coverage estimates in the fall of 2017. These data summarize over 1700 nationally representative, cross-sectional household surveys conducted as part of national censuses, DHS, MICS, LSMS and others [5].

This study uses global and country-level progress on the sanitation component of Goal 7 Target 10b of the MDGs from 1990–2015 with more detailed analysis of those households without 'improved' sanitation (Fig 1). The JMP is now monitoring a higher service level, 'safely

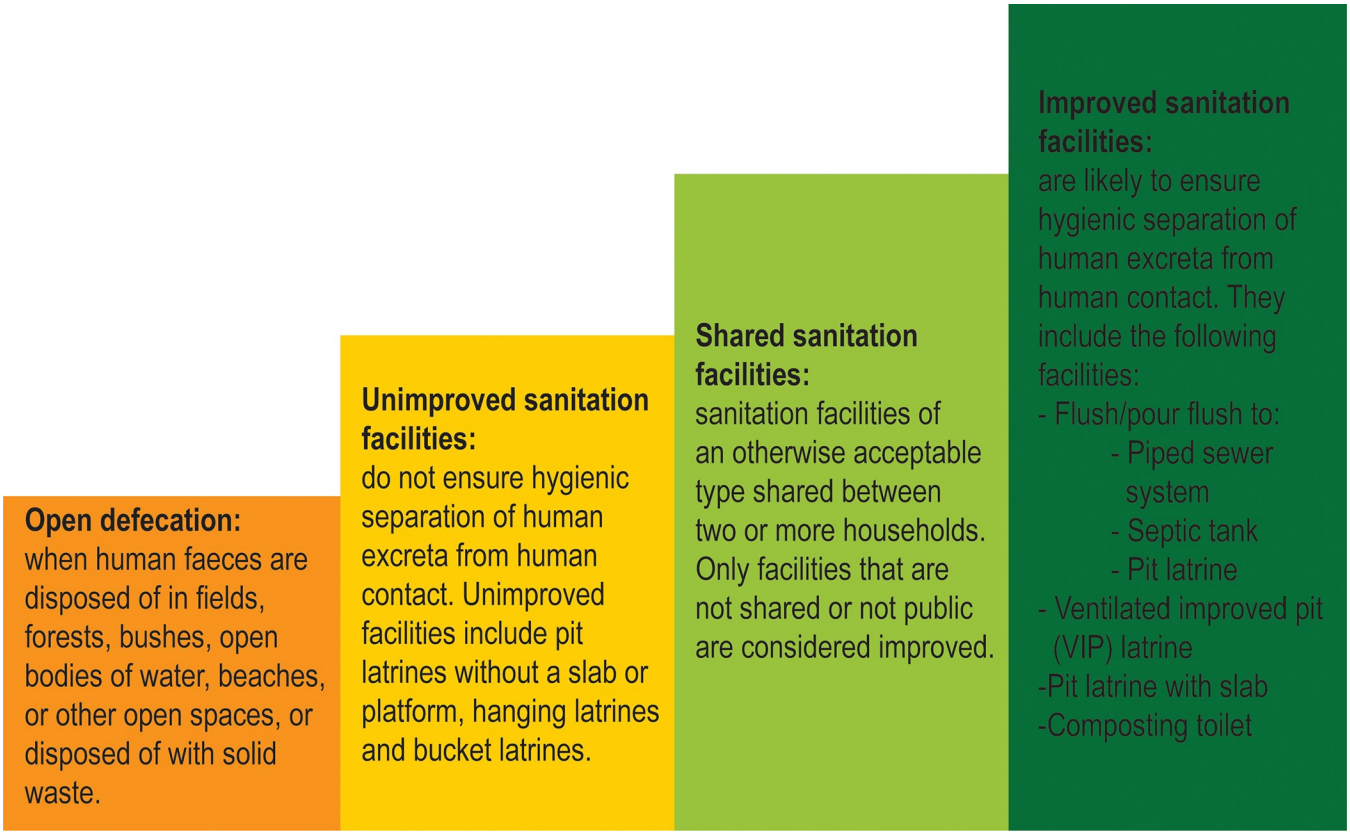

Fig 1. Sanitation indicator definitions used under the MDGs modified from: [24].

https://doi.org/10.1371/journal.pwat.0000002.g001

managed', that incorporates safe disposal of excreta or transportation for treatment off-site. The data for 'safely managed' are unavailable for nearly all countries during the MDG period, therefore this analysis focuses on four 'rungs' of the sanitation ladder (Fig 1).

Not every country included in the JMP data was included in this analysis. As described below, substantial effort was required to gap-fill missing data. Very small countries often differ systematically from their neighbors or other countries of similar development level. Therefore, countries that both (1) had incomplete JMP data and (2) had either a population of less than 100 thousand or a total area of less than 100 square kilometers were excluded from our analysis. In total, 190 countries, equivalent to 99.8% of the global population were included for the sanitation analysis (Table 1).

Table 1. Countries and population included in this analysis, with exclusion reasons.

Sanitation	
Countries included in raw JMP data (2017)	225
Countries excluded by size/population criteria	35
Total Countries used in analysis	190
Total world population included in the 190-country analysis	99.8%

Note: South Sudan became independent in 2011; because data for South Sudan were unavailable prior to independence, the data for Sudan and South Sudan remain aggregated through 2015 for this analysis.

https://doi.org/10.1371/journal.pwat.0000002.t001

Statistical analysis

The JMP sanitation data were downloaded directly from the JMP website (https://washdata.org/). The base sanitation data used for this analysis were downloaded from the JMP website after the final JMP report on the MDGs was published. The JMP gathers its data the rough national censuses and nationally representative household surveys. The data are collected by national offices of statistics as well as international survey initiatives. For the purposes of this analysis sanitation access was categorized by the categories improved, shared, other unimproved, and open defecation as defined by the WHO/UNICEF Joint Monitoring Programme (Fig 2).

Where JMP did not have country-level data for a specific needed value (e.g., shared sanitation coverage in rural areas of Angola in 1995) we gap-filled using an existing methodology [25]. In brief, countries were assigned to one of five "WASH clusters" (Table 2) according to similarities across a set of water and sanitation indicators using gap statistical analysis and hierarchical clustering by Onda and colleagues [26]. The mean value of the proportion of the population with access to each technology category with respect to the total population was

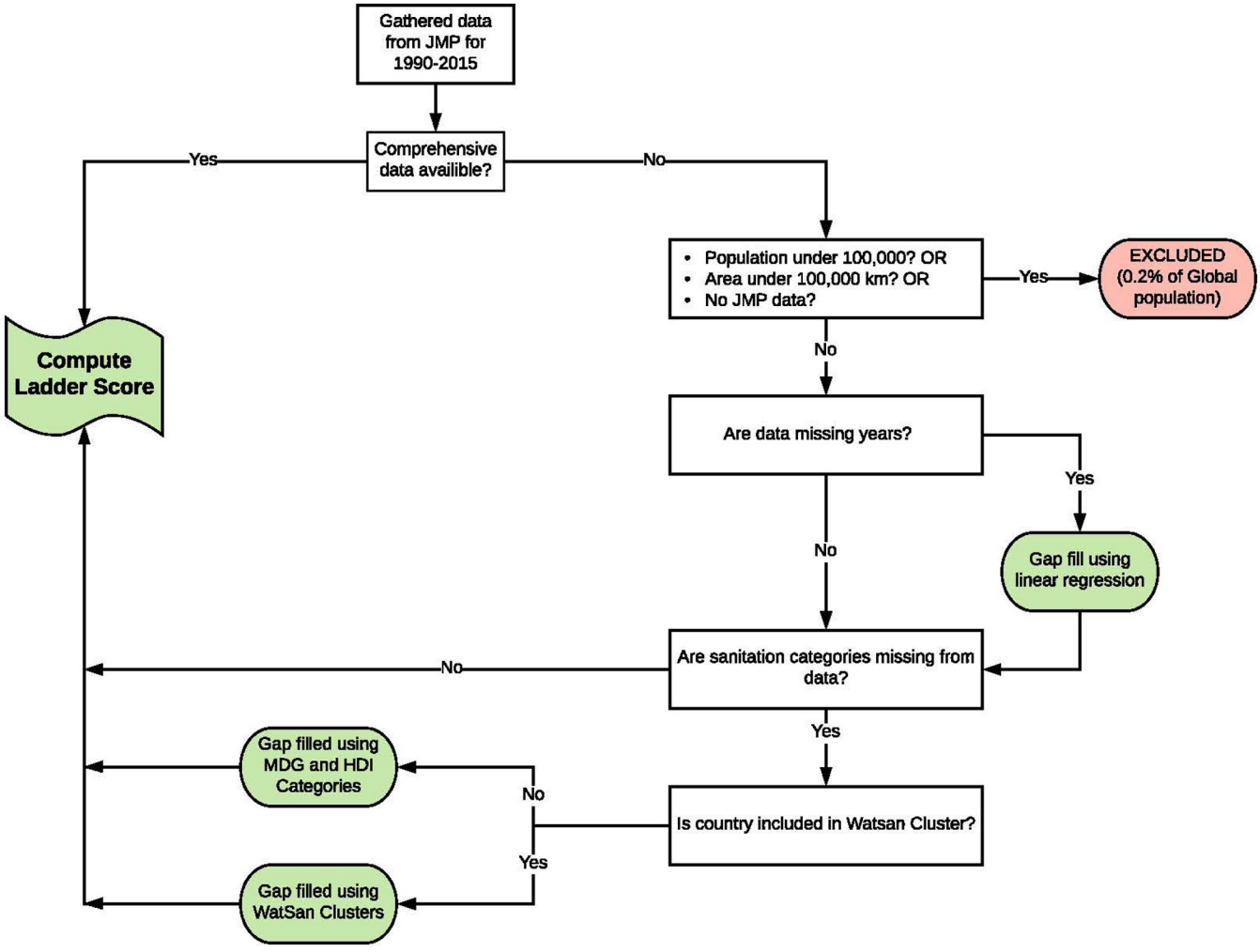

Fig 2. Decision tree used in gap-filling country-level data and country exclusion methodology.

https://doi.org/10.1371/journal.pwat.0000002.g002

Table 2. Countries included in this analysis and the water "clusters" identified by Onda and colleagues [26]. Countries in italics were filled based on cluster averages calculated by non-italicized countries.

Cluster	Countries
1	Australia, Austria, Belgium, Cyprus, Czech, Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Israel, Japan, Latvia, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, *Canada*, *Lithuania*, *Republic of Korea*, *Singapore*, *United States of America*
2	Argentina, Belarus, Brazil, Bulgaria, Colombia, Cuba, Iran (Islamic Republic of), Kazakhstan, Mexico, Russian Federation, Ukraine, Uruguay, *Chile*, *Oman*, *Venezuela (Bolivarian Republic of)*
3	Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Costa Rica, Croatia, Dominican Republic, Egypt, El Salvador, Georgia, Iraq, Jordan, Kyrgyzstan, Maldives, Mauritius, Mongolia, Republic of Moldova, Sri Lanka, Syrian Arab Republic, Tajikistan, TFYR Macedonia, Tunisia, Turkey, Viet Nam, *Algeria*, *Lebanon*, *Turkmenistan*, *Uzbekistan*
4	Belize, Bhutan, Botswana, China, Ecuador, Gabon, Guatemala, Guyana, Honduras, India, Indonesia, Jamaica, Namibia, Nicaragua, Panama, Paraguay, Peru, Philippines, Sao Tome and Principe, South Africa, Suriname, Thailand, Trinidad and Tobago
5	Afghanistan, Bangladesh, Benin, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Haiti, Kenya, Lao People's Democratic Republic, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Myanmar, Nepal, Niger, Nigeria, Pakistan, Papua New Guinea, Rwanda, Senegal, Sierra Leone, Sudan & South Sudan Combined, Swaziland, Timor-Leste, Togo, Uganda, United Republic of Tanzania, Yemen, Zambia, Zimbabwe, *Angola*, *Cape Verde*

https://doi.org/10.1371/journal.pwat.0000002.t002

found for each water and sanitation cluster. This value was used to gap fill where the country level data was not available.

This approach has been found to be superior to geographic or income-based clustering used by the United Nations and World Bank [26]; countries that were not included in this clustering analysis were gap filled using Human Development Index (HDI) and MDG region groupings. Mean values were developed from the resulting clusters and assigned where data was missing. These country clusters were also used to develop mean cluster level estimates for the proportion of the population using shared sanitation.

$$Ratio_{S/(I+S),Year} = \frac{\%Shared_{Year}}{\%improved_{Year} + \%Shared_{Year}} \quad (1)$$

Where entire years were missing in the data provided by JMP, estimates were made using simple linear regression with Microsoft Excel (2016). These estimates were based on available data points. Where there is no data available for sanitation, JMP reports these countries as having no shared sanitation. No shared sanitation in a country is probably unrealistic; thus, we used the mean cluster value for the ratio of shared sanitation to improved sanitation in both urban and rural areas and gap-filled country-level shared sanitation estimates using that ratio (Eq 1). A summary of the gap-filling methods used and the number of countries to which they applied is included in Table 3.

One fundamental difference between the Ladder Score and the MDG binary metric is the type of changes in sanitation coverage that are incorporated into the score. Fig 3A and 3B illustrate that only changes from lower categories to "Improved (not shared)" were included in the MDG metric. In contrast, all changes between categories are including in the Ladder Score.

The Ladder Score for each country was calculated by summing the percentage of the country's population on each rung after multiplying that percentage by the associated rung multiplier (Eq 2, Table 4).

A variety of rung multipliers were trialed in order to determine their impacts. There were no major differences when comparing the MDG scores against the Ladder Scores using differing

Table 3. Summary of countries affected by gap-filling.

Countries used to calculate cluster averages of shared to improved sanitation ratio	137
Countries missing shared sanitation estimates	36
Countries gap-filled using WatSan cluster methodology (Onda et al. 2011)	13
Countries gap-filled using MDG region and HDI methodology	22
Countries missing data for certain years and technologies	40
Countries gap filled using HDI only	2
Total Countries used in analysis	190
Total world population included in the 190-country analysis	99.8%

Notes: South Sudan became independent in 2011; because data for South Sudan were unavailable prior to independence, the data for Sudan and South Sudan remain aggregated through 2015 for this analysis. Not all gap-filling categories are mutually exclusive, some countries were gap filled using both linear regression and the cluster methodology.

https://doi.org/10.1371/journal.pwat.0000002.t003

rung multipliers. Additionally, there is not sufficient research on changes in health outcomes to justify a different weighting of these multipliers. These are the same conclusions come to by Kempster and Hueso in their sanitation service level gap analysis [8]. Since the rung multipliers did not have a major impact on the comparative analysis and there was no supporting research for a different weighting system, an equally weighted ladder rung system was chosen.

$$Ladder\ Score = \sum Rung\ Multiplier * \%\ of\ Population\ on\ Rung \tag{2}$$

Categories of country-level sanitation progress

The JMP established progress categories to group countries based on their progress toward the sanitation MDG [16, 27]. These categories were based on an established target to be reached by 2015 for each country (Eq 3).

$$Target_{2015} = \%Improved_{1990} + \frac{100\% - \%Improved_{1990}}{2} \tag{3}$$

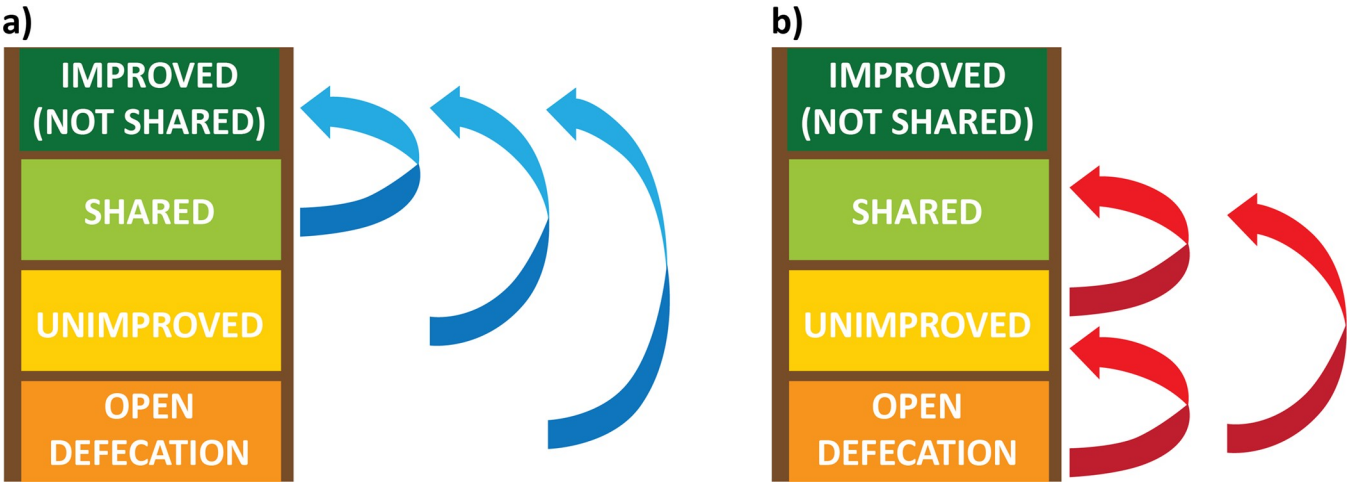

Fig 3. Illustration of the possible improvements in sanitation service level among the four categories reported by JMP and how they are incorporated into the MDG binary metric. (a) Using the binary metric applied during the MDGs, only progress moving population to the top of the ladder ("Improved") received credit toward the target, (b) types of progress that did not receive credit on the MDG target include moving a family from open defecation to shared use of an improved sanitation facility. Major improvements such as households upgrading from OD to a shared latrine were not counted under the MDGs; all changes shown in a and b receive credit when using the Ladder Score.

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Table 4. Ladder rungs and their multipliers.

Ladder Rung	Applicable SDG Term(s)	Rung Multiplier
Improved	*Safely Managed + Basic*	1
Shared	*Limited*	0.67
Other Unimproved	*Unimproved*	0.33
Open Defecation	*Open Defecation*	0

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Countries that closed the gap to within one percentage point of their target %-Improved in 2015 (using the "reduce by half" from 1990–2015 formulation) were classified as having "Met" the target. Those countries that closed two-thirds or more of the gap from the baseline to the target, but did not qualify as having "Met" the target were classified as having made "Good Progress"; those that closed one-third to two-thirds of the gap were classified as having made "Moderate Progress." Countries that did not close at least one-third of the gap (and those that regressed) were classified as having made "Little or No Progress."

These same classifications were used to categorize countries with respect to progress on the Ladder Score. The Ladder Score in 1990 was used as the baseline.

Results and discussion

This section addresses 1990–2015 progress on the Sanitation Ladder Score in comparison to progress on the sanitation MDG binary Improved/Unimproved metric. The first subsection covers global progress, including a comparison of Ladder Score vs. MDG. The second subsection address country-level progress, first identifying differences in country-level progress on the Ladder vs. MDG sanitation metrics for 190 countries representing 99.8% of the global population. This is followed by a focus on six illustrative countries that made notable progress on the sanitation ladder, with pie-charts to illustrate urban/rural ladder progress, with discussion and references that may yield insight into how this progress was achieved.

Global progress

Globally and for most countries, progress in closing the gap on the Sanitation Ladder Score outstripped progress closing the gap on the MDG binary metric. The overall global Ladder Score increased from 62.5 in 1990 to 76.7 in 2015, closing 38% of the gap. In contrast, using the MDG binary metric, the percentage of the population with "Improved" sanitation increased from 53% in 1990 to 67% in 2015, closing 30% of the gap. As illustrated in Fig 4, progress in the Ladder Score from 1990–2015 included substantial declines in the percentage of the global population practicing open defecation (from 24% to 13%) and using an unimproved sanitation technology (from 18% to 11%); use of both shared improved facilities (from 5% to 9%) and improved facilities (from 53% to 67%) increased. However, like the MDG target's "reduce by half" formulation, evaluating progress based on the percentage of the gap closed inherently benefits from a higher baseline value. The Ladder Score had a higher 1990 baseline than the binary percent improved metric used for the MDG. When evaluating progress based on raw percentage point increase, the global Ladder Score and the MDG metric improved by approximately 14.3 and 14.1 percentage points, respectively, between 1990 and 2015.

There is no inherent reason why progress on the two metrics should be so similar. A community, for example, in which a large number of households with Shared facilities receive their own individual facilities would yield only 1/3 the progress on the Ladder Score (0.67 → 1.0) that it would on the MDG score (0 → 1.0). It is a coincidence that global progress on the two

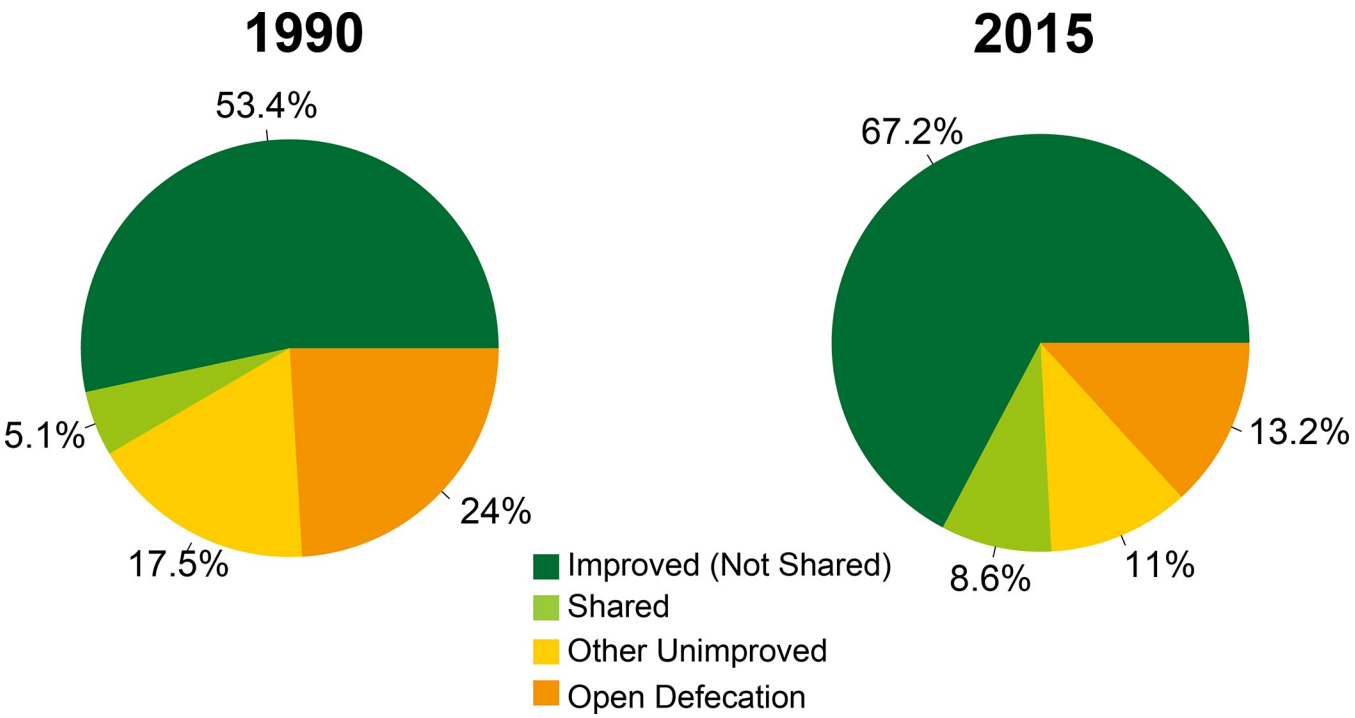

Fig 4. Overall global Ladder Score (left) and MDG % Improved (right) for 1990 and 2015.

https://doi.org/10.1371/journal.pwat.0000002.g004

metrics was so similar, meaning that globally the population receiving some Ladder Score credit for moving up the bottom three rungs of the ladder was nearly offset by the population receiving less credit for moving from rungs two and three on the ladder to the top rung. In many countries, progress varied widely between the Ladder Score and MDG metric, likely reflecting different approaches and strategies to improving sanitation coverage at national level (Fig 5).

In 2015, as the MDG period was drawing to a close, the JMP began to use categories to express the degree of progress from the 1990 baseline toward the target that had been achieved in individual countries: "Met" (within 1% of target), "Good progress" ($\geq$2/3 of the gap to target was closed, but not "Met"), "Moderate progress" (1/3-to-2/3 of the gap was closed), "Limited or no progress" ($<$1/3 the gap closed). As described in Methods, we used these same categories to evaluate 1990–2015 progress on the Ladder Score in individual countries. The following section addresses country-level coverage and differences between MDG and ladder progress at the country level.

Country-level progress

Sanitation ladder progress for all 190 countries in our analysis (constituting 99.8% of global population) can be downloaded from https://melliott.people.ua.edu/data.html; this includes the baseline 1990, 2000 and 2015 Sanitation Ladder Score for each country and estimates for all four ladder rungs across the country as a whole (total), urban and rural populations. Forty-one countries total achieved better categorical progress on the Ladder Score than on the MDGs. These countries are listed in Table 5; categorical progress on the MDG metric and the Ladder Score are listed for all 190 countries in the analysis in the data tables that can be downloaded from https://melliott.people.ua.edu/data.html. Countries like Ghana, Ethiopia and Cambodia that made notable achievements with respect to elimination of open defecation

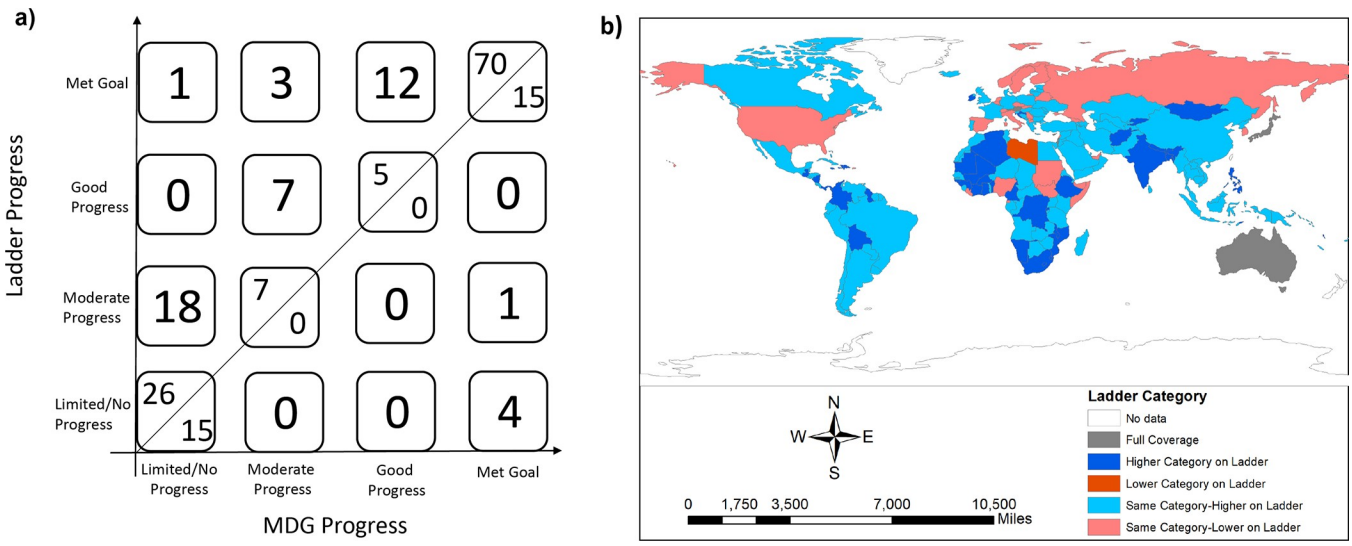

Fig 5. Progress from 1990–2015 across the MDG and ladder score among all 190 countries in our analysis using the categorical definitions of progress established by JMP. (a) 138 countries that were in the same progress category are divided by the diagonal line indicating whether the country closed a larger percentage of the gap on the Ladder or MDG metric, and (b) global map illustrating country-level categorical progress on the Ladder Score vs. MDGs. An additional six countries closed 100% of the sanitation gap; they thus fall directly on the line in the "Met Goal" category and are not included in the figure. The countries with different categorical progress across the MDG and Ladder Score metrics are also listed in Table 5. Some wealthy countries with very high 1990 and 2015 coverage (e.g., USA, Spain, Switzerland, Sweden) showed slightly less progress on the ladder, either due to a slightly higher 1990 baseline ladder score than 1990 MDG score or because of a slight increase in the modeled % Shared. The base layer of the map is from naturalearthdata.com.

https://doi.org/10.1371/journal.pwat.0000002.g005

and/or increase in population on shared sanitation are notable among those in Table 5 and are discussed below. All outputs from our analysis are available in Microsoft Excel format at melliott.people.ua.edu/data.html.

There are diverse approaches and pathways to progress on the Sanitation Ladder. Below are figures illustrating the 1990 and 2015 sanitation status of six countries that made notable progress on the Sanitation Ladder and a short discussion of the nature of that progress with supporting references. Only two of these six countries (Ghana and Ethiopia) fell into a different category of total national progress on the Ladder Score than they did on the MDGs. However, all made remarkable urban and/or rural progress from their baseline coverage and their approaches could provide valuable lessons for other countries trying to progress on the SDGs. A map of the countries discussed in this section is included in a S1 Fig.

Country progress profile 1: Cambodia. In 1990, Cambodia had 89% overall OD and a Ladder Score of 5.7; by 2015, Cambodia was among the global leaders in ladder progress, increasing overall Ladder Score from 5.7 to 48.6 (Fig 6). This includes an increase in rural Ladder Score from 2.1 in 1990 (94% OD) to 36.2 (31% improved, 60% OD) by 2015. In urban areas, Cambodia had the greatest increase in Ladder Score globally from 1990–2015, 71.2 points, from 24.9 to 96.1; this urban progress occurred while the urban population was increasing by about 2.5x [28].

The Government of Cambodia opted to establish its own 2015 goals for sanitation, with separate urban and rural targets that were more modest than the MDGs (targets of 74% urban and 30% rural coverage, equating to 40% overall). But these were intermediate targets for sequential longer term targets leading to a goal of universal coverage by 2025 [29]. Urban sanitation coverage in Cambodia is driven by success in Phnom Penh, where the famously successful water utility has leveraged its success to improve sanitation coverage by including a 10% surcharge for sanitation services; however, there are still major challenges in secondary cities and small towns [29].

Table 5. Countries that made greater categorical progress on the ladder score than on the MDG binary metric.

MDG to Ladder Score Shift	Region (No. of Countries)	Countries
Good to Met	Latin America and the Caribbean (5)	Colombia, Dominican Republic, Guyana, Nicaragua, Panama
	Northern Africa (1)	Algeria
	Oceania (1)	Vanuatu
	South-eastern Asia (1)	Philippines
	Southern Asia (3)	Bangladesh, Bhutan, Nepal
	Sub-Saharan Africa (1)	Rwanda
Moderate to Met	Caucasus and Central Asia (1)	Kyrgyzstan
	Sub-Saharan Africa (2)	Mauritius, South Africa
Limited to Met	Developed (1)	Croatia
Moderate to Good	Eastern Asia (1)	Mongolia
	Latin America and the Caribbean (2)	Bolivia (Plurinational State of), Guatemala
	Southern Asia (1)	India
	Sub-Saharan Africa (3)	Ethiopia, Malawi, Mauritania
	Developed countries (1)	Ireland
	Latin America and the Caribbean (2)	Haiti, Jamaica
Limited to Moderate	South-eastern Asia (1)	Timor-Leste
	Southern Asia (1)	Afghanistan
	Sub-Saharan Africa (13)	Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Democratic Republic of the Congo, Ghana, Guinea, Guinea-Bissau, Lesotho, Mali, Mozambique, Namibia, Swaziland

[1] –Five countries made less categorical progress on the Ladder metric than the MDG metric from 1990–2015. Libya, Seychelles, Granada, Aruba and French Polynesia.

https://doi.org/10.1371/journal.pwat.0000002.t005

In rural areas, the World Bank, NGOs and local private enterprise have been essential in developing and supplying appealing and affordable latrines [30]. Despite substantial progress in demand-driven rural sanitation, OD is still very common among the rural poor [31]. The Royal Government of Cambodia has targeted elimination of OD by 2025, focusing on district and province-level demand generation, with partners focusing on market-based scale-up [31, 32].

Country progress profile 2: Lao People's Democratic Republic (PDR). Lao PDR (often referred to as Laos) shares a border with Cambodia and also made remarkable progress on sanitation coverage during the MDG period while undergoing substantial rural to urban migration (from 15.4% urban population in 1990 to 33.1% in 2015) [28]. In 1990, Laos had 85% overall OD, and a Ladder Score 10.4 (Fig 7). By 2015, Laos had recorded the greatest increase globally in overall Ladder Score, from 10.4 to 73.7 (63.3 points). Like Cambodia, Lao PDR had strong progress across both rural and urban areas. The rural Ladder Score increased from 2.1 in 1990 (with 94% OD) to 58.8 (56% Improved, 37% OD) and the urban Ladder Score increased from 55.9 (50% improved, 35% OD) to 97.4 (96% improved, 1% OD).

The Government of Laos has taken an active role in collaborating with development partners and international NGOs on community-led total sanitation (CLTS) and declaring ambitious 2020 Basic sanitation targets of 100% for urban and 80% for rural areas [33] and national open defecation free (ODF) status by 2025 [34]. While overall sanitation progress has been

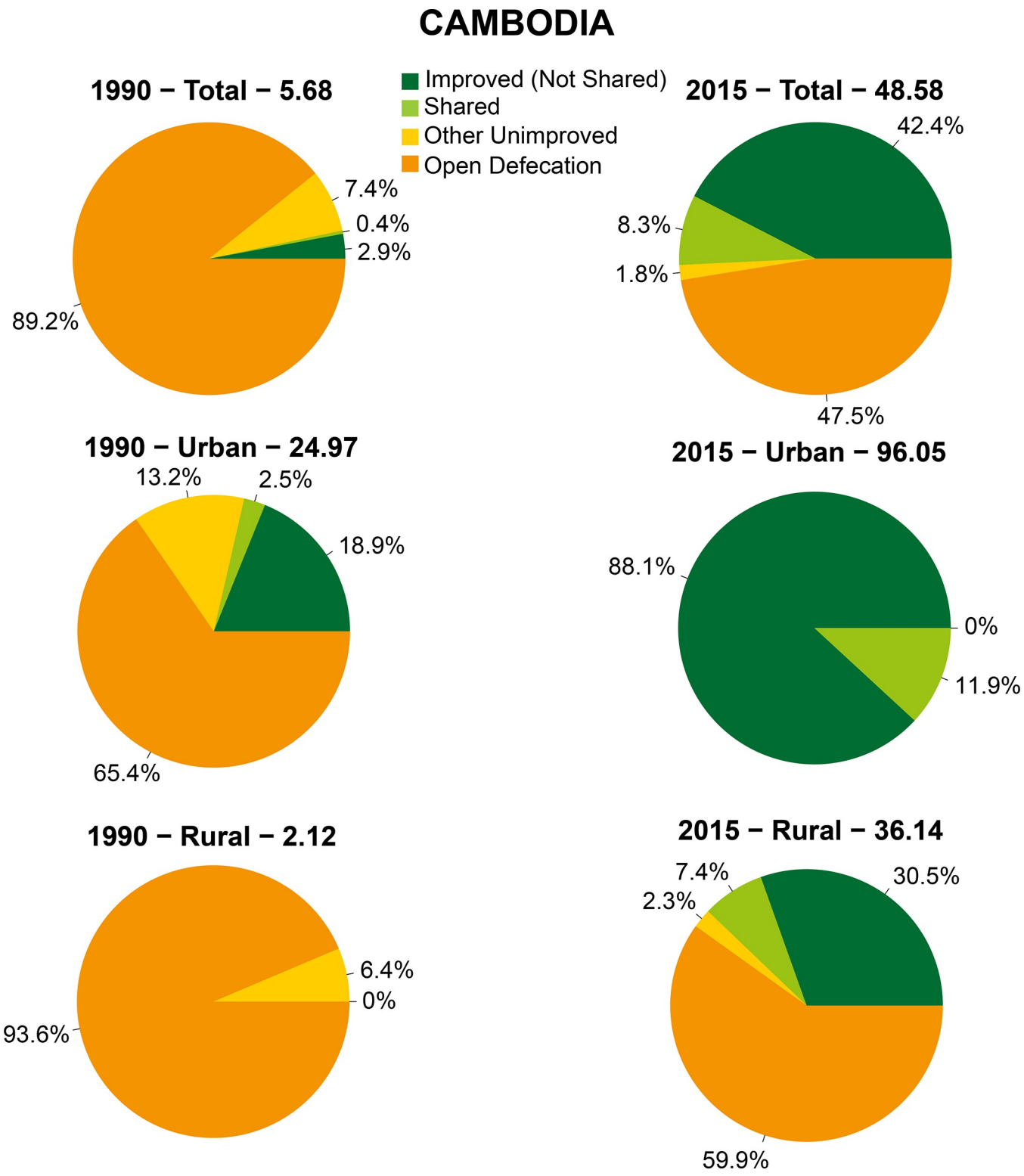

Fig 6. Total (top), Urban (middle) and Rural (bottom) sanitation ladder coverage in Cambodia for 1990 (left side) and 2015 (right side), with Ladder Score for each condition above the pie chart.

https://doi.org/10.1371/journal.pwat.0000002.g006

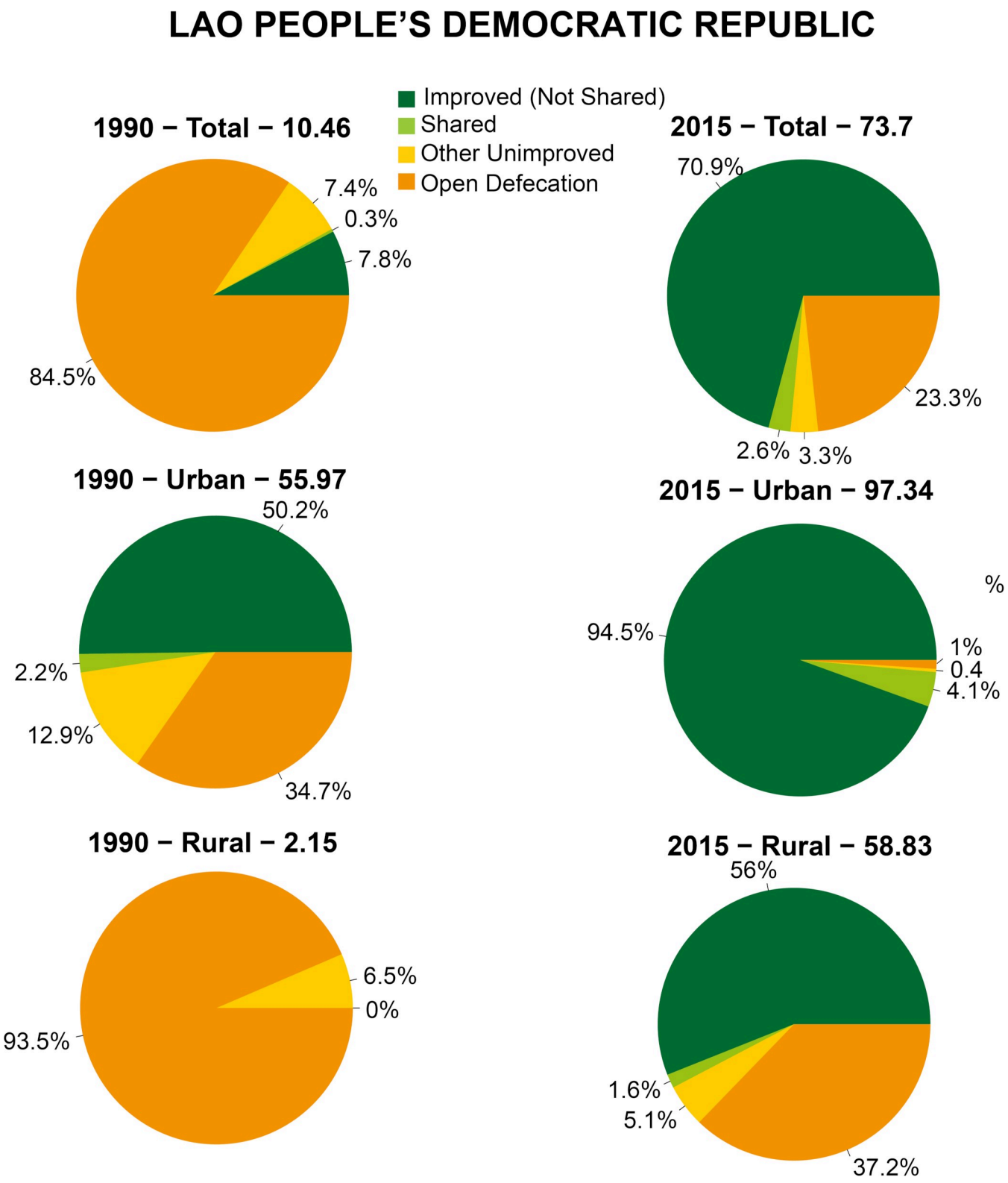

Fig 7. Total (top), Urban (middle) and Rural (bottom) sanitation ladder coverage in Lao PDR for 1990 (left side) and 2015 (right side), with Ladder Score for each condition above the pie chart.

https://doi.org/10.1371/journal.pwat.0000002.g007

among the best in the world, inequality in rural areas is still a concern. Absolute inequality by wealth in urban sanitation coverage decreased substantially in sewered urban areas while simultaneously increasing in rural areas [35]. A probable explanation is lack of Government hardware funding for rural sanitation, with most coming from NGO budgets and investment of private households [33]. While CLTS has been a driver for rural sanitation progress, participation has been mostly among wealthy households; the World Bank and others are trying to facilitate access to less expensive sanitation technologies [36]. Provision of public water supply to villages has reportedly been contingent upon adoption of CLTS, a strategy meant to leverage desire for piped water access to increase sanitation coverage [37]; this is analogous to the practice in wealthy countries of linking drinking water and wastewater bills as the threat of shutting off water service is often used to compel payment for both services (wastewater service typically cannot be shut off for non-payment due to the threat to public health).

Country progress profile 3: Ethiopia. Ethiopia's Sanitation Ladder Score increased from 5.6 in 1990 to 47.2 in 2015 (Fig 8). During this time, Ethiopia had the largest percentage point decline in OD, going from 92% to 29%. While this 63-percentage point decline is remarkable, the majority of progress was not captured by the MDG metric. This shift in population-level sanitation resulted in substantially increased use of unimproved sanitation technologies (1% to 28%) and shared sanitation (4% to 14%) alongside improved sanitation (3% to 28%).

Ethiopia is widely regarded as an MDG success story. The WHO reports that progress across a broad range of health-related MDGs, including sanitation, was achieved in Ethiopia "when the government and development partners have a common vision and work together" [16]. Other sources also cite government and UN support in the context of strong inclusive economic growth [38]. However, others note that with continued economic growth will come decreasing donor support and the challenge of improving an inefficient tax system and ensuring that tax revenues are allocated to health [39]. Looking beyond the MDG sub-target for sanitation, there is evidence that actual sanitation service levels in small- and medium-sized towns are poor (e.g., latrines lacking slabs, ventilation, handwashing facilities) and that service level is strongly positively correlated with wealth [40].

Country progress profile 4: Nepal. Nepal was among the countries with the largest progress on the national Ladder Score from 1990 to 2015, increasing from 7.9 to 59.3 (Fig 9). Nearly 90% of Nepal's population practiced open defecation in 1990, including over 90% of rural dwellers and one-third of urban residents. By 2015, the percentage practicing OD had declined to roughly 31%, with 64% using either improved or shared sanitation technologies. The UNDP reported that the success of Nepal was largely due to a "massive ODF campaign" and better coordination of stakeholders [41]. The UNDP report also cites the implementation of the MDG Acceleration Framework (MAF) as a key to resolving Nepal's challenges with lagging progress of some subnational regions and population groups.

In early 2016, the Government of Nepal established a new Ministry of Water Supply and Sanitation, demonstrating a continuing commitment to coordination and success on the WaSH-related SDG targets [41]. Nepal's remarkable success on the sanitation ladder during the MDG period and its prioritization of sanitation for the SDGs provide many valuable lessons for countries struggling to achieve the sanitation targets of the SDGs.

Country progress profile 5: Ghana. The approach toward sanitation coverage taken in Ghana focused mainly on transitioning from other unimproved and OD to shared sanitation, with significant progress made in both rural and urban areas. In 1990, 22 percent of the population practiced open defecation and 42 percent only had access to unimproved sanitation technology (Fig 10). By 2015 access to either shared sanitation or improved sanitation had increased in Ghana from 36 percent to 75 percent of the population. Shared sanitation accounted for the majority of this progress in both rural and urban areas.

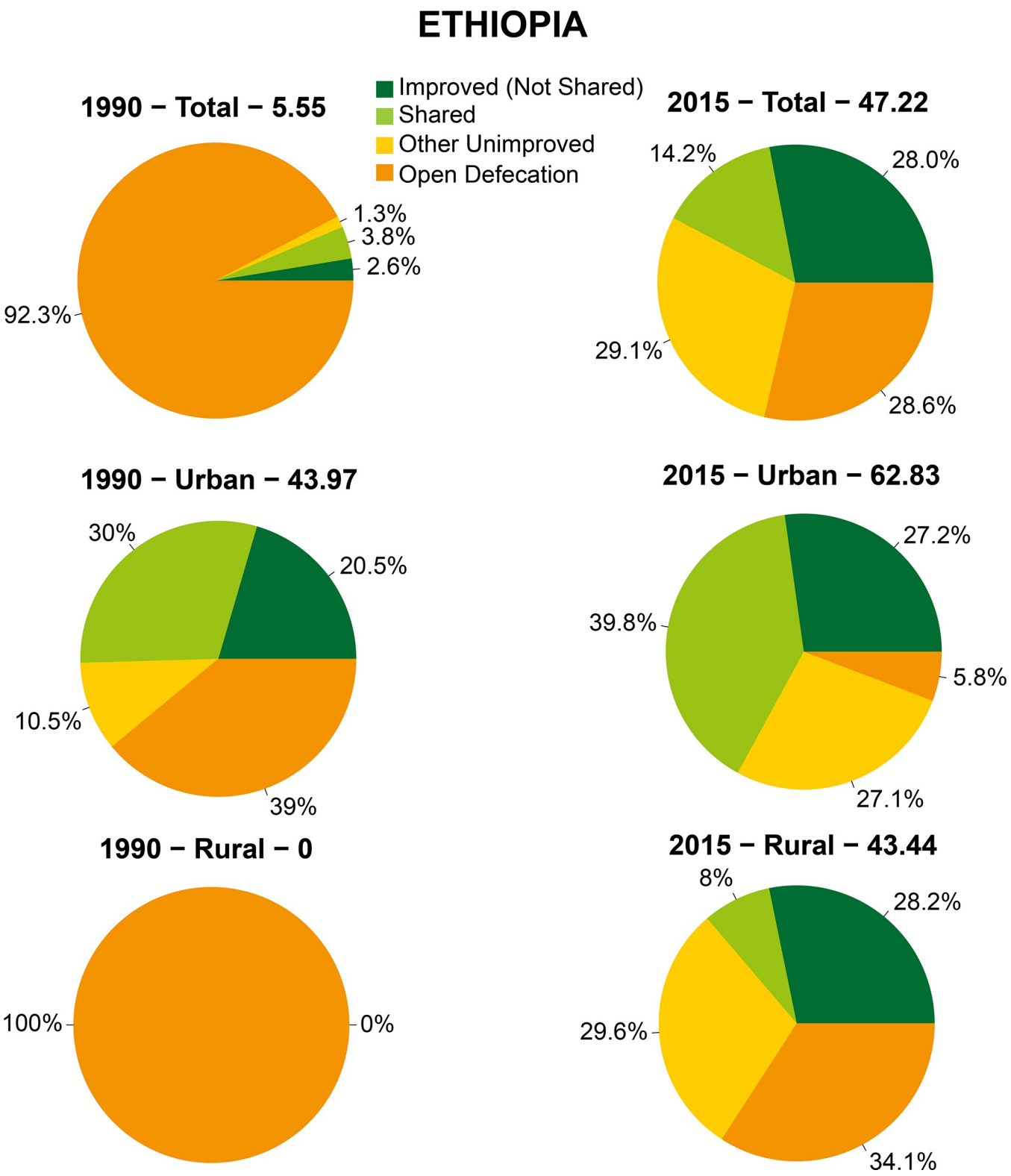

Fig 8. Total (top), Urban (middle) and Rural (bottom) sanitation ladder coverage in Ethiopia for 1990 (left side) and 2015 (right side), with Ladder Score for each condition above the pie chart.

https://doi.org/10.1371/journal.pwat.0000002.g008

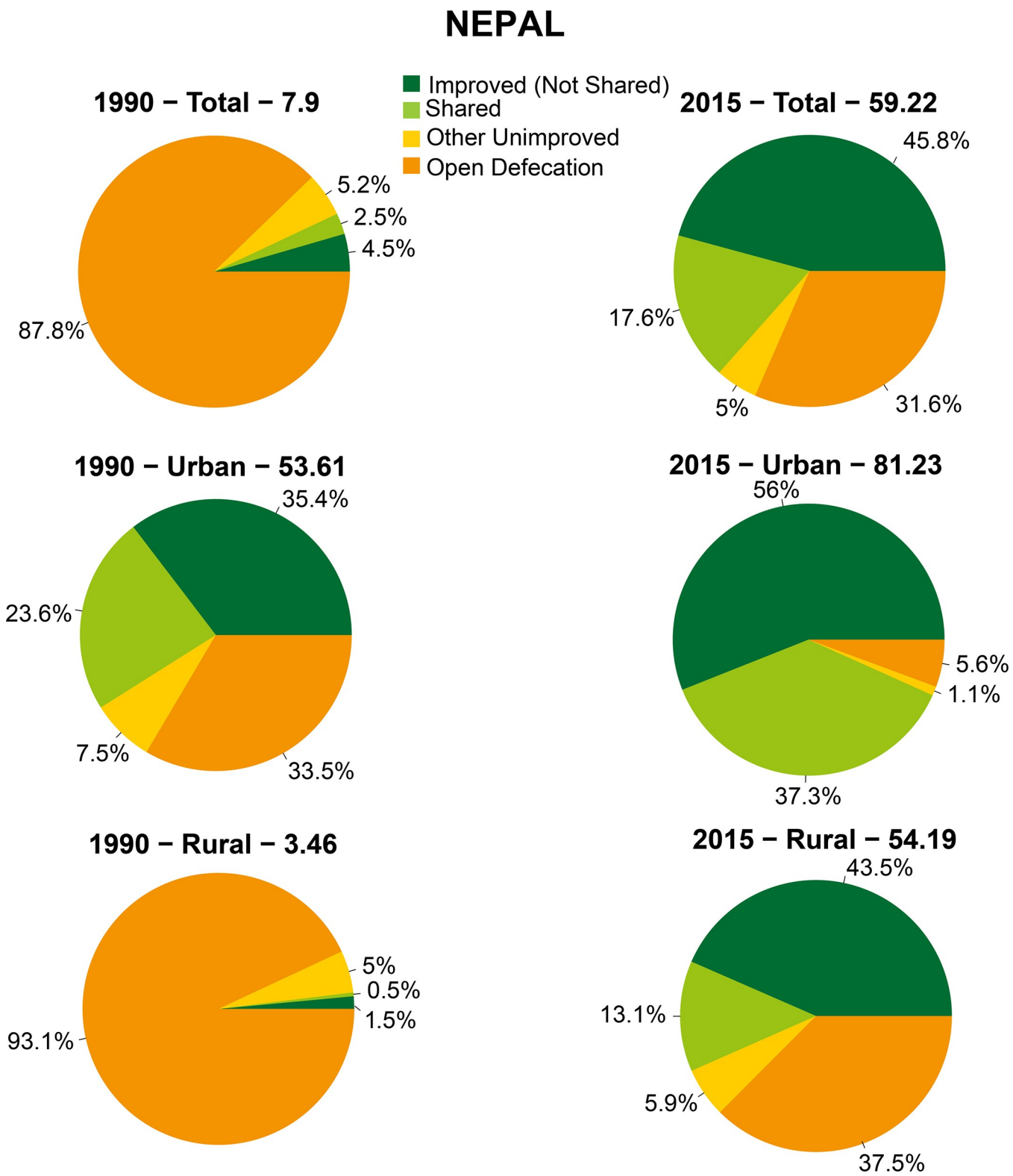

Fig 9. Total (top), Urban (middle) and Rural (bottom) sanitation ladder coverage in Nepal for 1990 (left side) and 2015 (right side), with Ladder Score for each condition above the pie chart.

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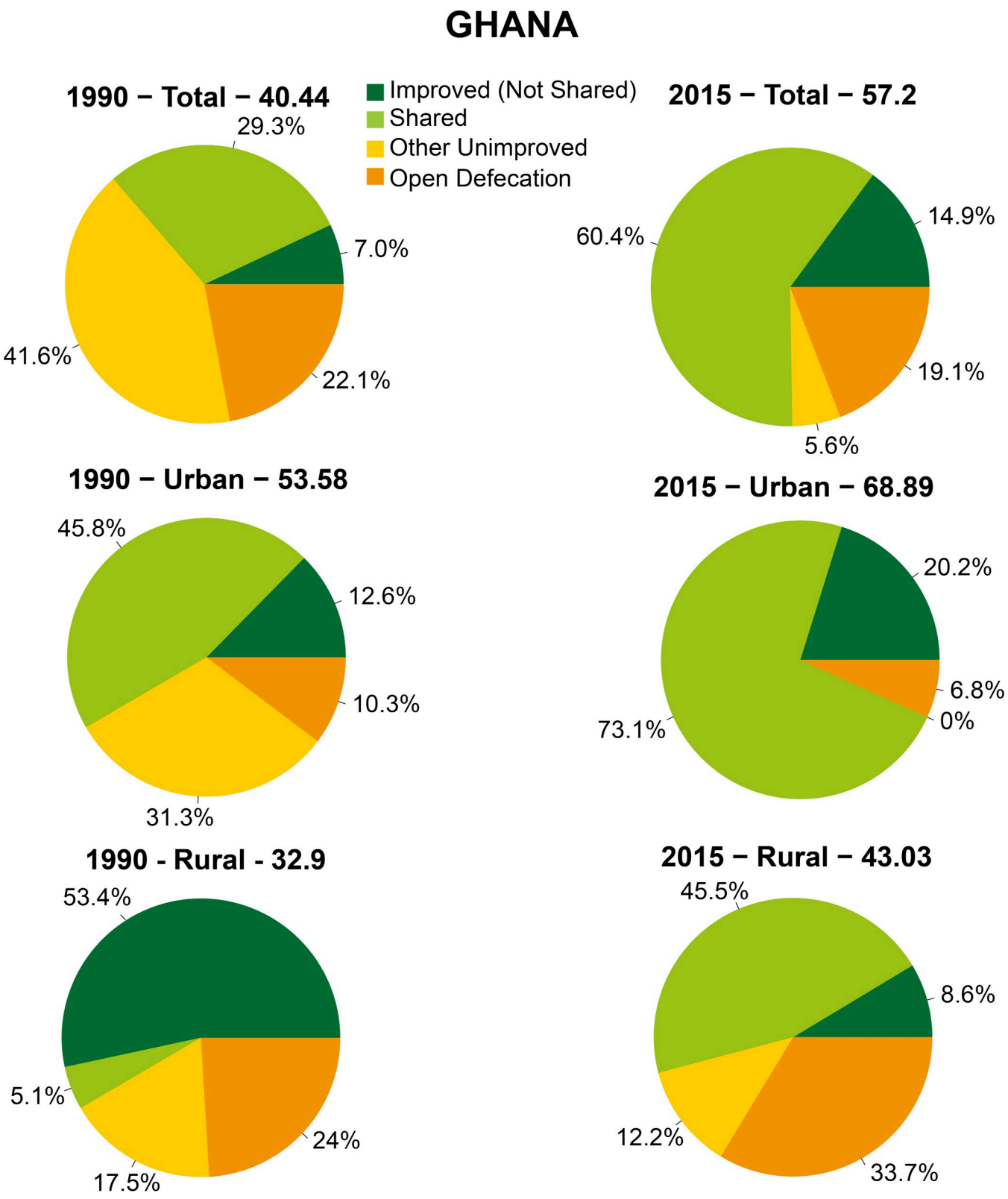

Fig 10. Total (top), Urban (middle) and Rural (bottom) sanitation ladder coverage in Ghana for 1990 (left side) and 2015 (right side), with Ladder Score for each condition above the pie chart.

https://doi.org/10.1371/journal.pwat.0000002.g010

In Ghana, 79% of the population lives in compound houses that are traditionally shared by extended families [42]. The vast majority of these compound houses rely on shared sanitation. This cultural practice, combined with other economic and societal factors has made shared sanitation a popular solution in Ghana, with 1/3 of the population preferring shared sanitation to single-household toilets; which are expensive to build and maintain and for those in informal settlements [42]. In 2006, Ghana introduced the second phase of its' Growth and Poverty Reduction Strategy which included the goal of enforcing laws on the provision of sanitation facilities by landlords and slum upgrading by providing basic services in urban areas [43]. This targeted approach to upgrading sanitation in compound housing and urban slums, combined with a national preference for shared sanitation explain Ghana's success in expanding sanitation access through shared sanitation. Ghana's unique approach to addressing the MDGs provides a blueprint for countries with similar cultural norms to make significant progress toward improving sanitation service level and protecting health.

Country progress profile 6: Poland. Poland was categorized as a developed country during the MDG period, and like other developed countries it started with a relatively high baseline in 1990, however over 16% of the population were still using unimproved technologies (Fig 11). Unlike the other five countries covered in detail here, Poland's progress was nearly exclusively in shifting households from unimproved sanitation technologies to improved technologies used by a single household. This type of progress receives more credit on the MDG metric than on the Ladder Score, thus Poland made notably more progress on the former (14.5 percentage points) versus the latter (9.8 percentage points). Progress was particularly strong in rural areas, where only 65% of the population had access to improved sanitation in 1990 compared with 97% in 2015.

In 1993 the Polish Association of Public Health was founded [44]. This was a part of a larger shift in from the late 1980s to the early 1990s toward a focus on Polish public health and formalizing institutions to support public health in Poland. Despite large gains made in Poland there is still much work to be done to meet the SDG "Safely Managed" criterion. In rural areas, only 42% of the population has access to a piped sanitary sewer system. A popular alternative is the use of holding tanks where untreated wastewater is stored for long periods of time [45]. The wastewater from these holding tanks is pumped and transported to centralized wastewater treatment plants for treatment. However, the high cost of pumping encourages tank users to decrease water use; therefore, the treatment processes in plants receiving a high proportion of wastewater from tanks can be adversely affected by the higher solids content and strongly anaerobic conditions. Additionally, leaks are often a problem with these tanks and pose a threat to surface and groundwater since the sewage stored is untreated [45].

Additional countries of interest. The countries highlighted above provide examples of different approaches to sanitation progress under the MDGs and from different baseline conditions. Four of these (Cambodia, Lao PDR, Ethiopia and Nepal) made among the greatest progress on the Sanitation Ladder Score between 1990–2015; all four of these countries had over 90% rural OD in 1990 and made major progress by 2015. This rural progress was supplemented with substantial progress in urban areas, particularly in Cambodia and Lao PDR. The diverse approaches used in these four countries may provide insight on how to eliminate OD and increase Basic sanitation under the SDGs. The sanitation strategies documented in other countries with high OD may also provide insight, for example Haiti [46, 47] and Rwanda [48, 49]. Ghana provides an example of an approach based on shared sanitation that could yield progress on preventing disease, even though it may not contribute substantially to global sanitation targets. While the success of Ghana's shared sanitation may be dependent on cultural housing norms [42], there is reason to believe that in some settings, including slums in India, that shared public sanitation may be the best current option [18]. Poland may provide useful

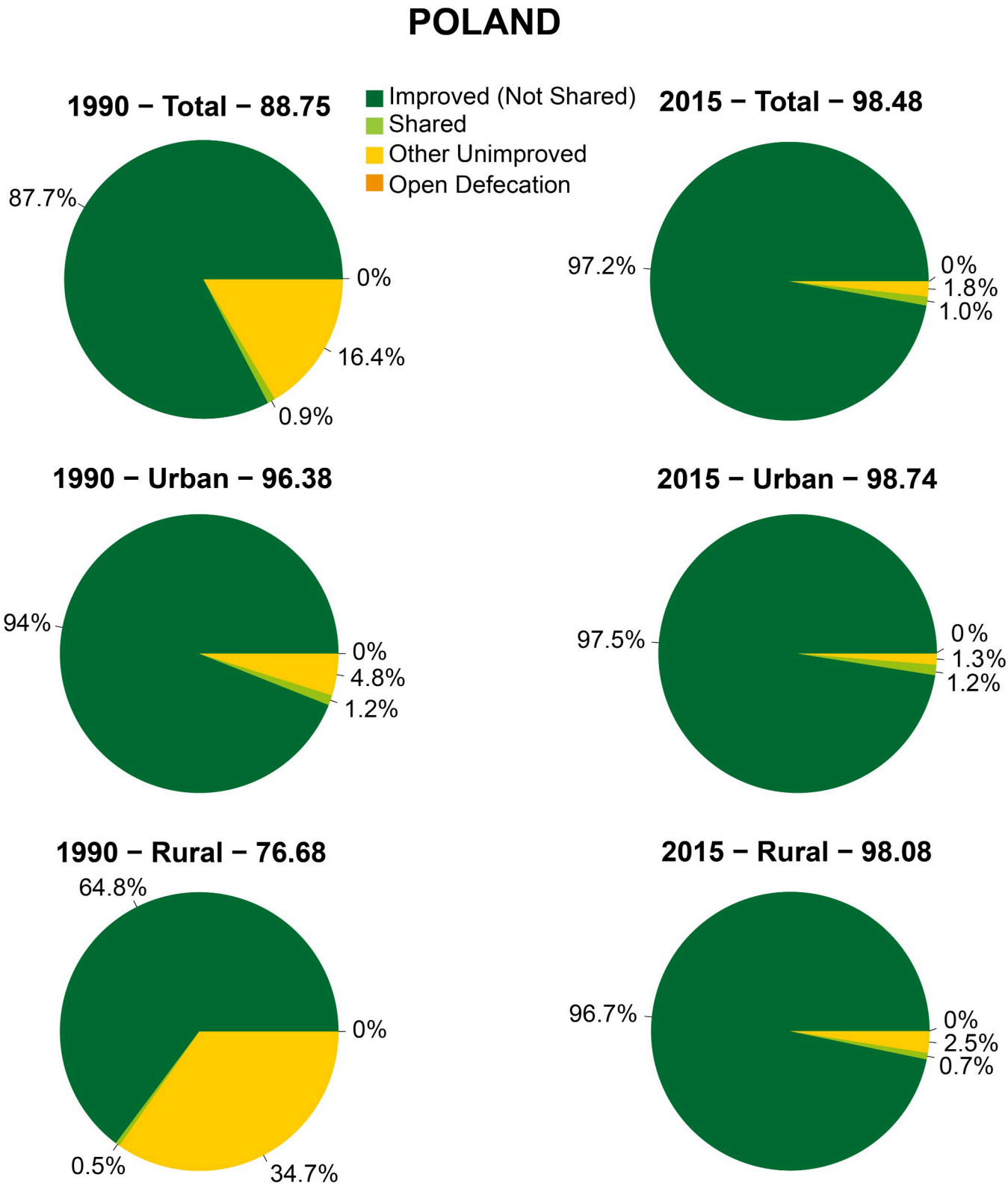

Fig 11. Total (top), Urban (middle) and Rural (bottom) sanitation ladder coverage in Poland for 1990 (left side) and 2015 (right side), with Ladder Score for each condition above the pie chart.

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insight on how substantial progress can be made toward universal basic sanitation in upper-middle and high-income countries that are lacking coverage particularly in rural areas [44, 45]; Montenegro [50] and Albania [51] also made progress from their 1990 baselines, with distinct challenges and approaches.

MDG ladder progress, the SDGs, and health

The world is far behind the rate of progress required to achieve the SDG for sanitation [52]. Since 2000, the global annual increase in basic sanitation coverage of about 1% lags far behind the required rate of at least 3% [53]. The SDG 6 Global Acceleration Framework and others [53, 54] have proposed diverse approaches to increase progress in sanitation coverage to meet the SDG. While these proposals acknowledge that some countries have made rapid progress and there is an emphasis on better use of available data, there remains a need to identify and learn from countries that have made rapid progress at a national level or sub-national level with regard to urban or rural settings for example.

The sanitation targets for the SDGs and the MDGs differ, but data from the MDG period provide a robust multi-decade, real-world data source for identifying policies, practices and factors that could enable rapid progress toward the SDG sanitation targets. This rich database offers an opportunity to study the approaches that enabled some countries to make rapid urban and/or rural progress toward the sanitation sub-target of the MDGs, and to consider how these lessons might be adapted to other countries and settings. We hope that our effort to supplement JMP data collection will enable deeper analysis of country-level, urban and rural progress across the sanitation ladder and support more rapid progress toward achieving SDG 6.

While it is widely accepted that adequate sanitation is necessary to reduce exposure to fecal-oral pathogens and protect health, there are diverse exposure routes for fecal-oral pathogen exposure, particularly for young children [55–57]. Additionally, the population-level health improvements seen in wealthy countries over the first half of the 20th-century were often achieved in the context of widespread provision of centralized water and wastewater services [58, 59]. While progress on the sanitation ladder is likely to be beneficial for population health, it is unclear that all aspects of progress to a given rung on the ladder will yield the same benefits.

Limitations

The household survey data and methods used for this analysis draw from those used by the JMP, so the same general limitations apply. For example, estimating sanitation coverage using linear regression with time means that early (e.g., 1990) point estimates of coverage will change retroactively when later data (e.g., from 2015) are added [5]. While critiques of the JMP methodology should be acknowledged, it is the gold standard for global sanitation coverage data. Thus, any analysis of global sanitation coverage should build upon JMP.

Household surveys form the basis of global sanitation estimates and the underlying data inherit the typical limitations and biases of surveys. Evidence that interviewees underreport the use of less safe household sanitation facilities has been reported [60] and non-household sanitation use was not included in the MDGs [61]. There is also a documented bias toward surveys taking place in the dry season [62]. The main datasets (e.g., DHS, MICS, national censuses) have been assembled from different surveys that may have changed incrementally over time [63]. Additionally, the JMP data do not have publicly available margins of error, so it is not possible to estimate confidence intervals.

This analysis expands on the JMP dataset by gap-filling to acquire comprehensive data across the four ladder rungs for which data were monitored 1990–2015. Because the main

purposes of this work are to demonstrate the efficacy of a single score to represent progress across the sanitation ladder and to provide the most comprehensive analysis of sanitation ladder progress over the MDG period, the findings are not necessarily weakened. Incorporation of a sanitation score that differentiates "Safely Managed" from "Basic" would require a modified Ladder Score metric as noted by Kempster and Hueso (Kempster & Hueso, 2018b). Further analysis is needed to accurately assess sub-national trends that may differ substantially from the national patterns discussed here. Also, this analysis includes urban:rural disparities at the national level but socioeconomic, ethnic and other inequalities and disparities are not addressed.

Emerging evidence indicates that sanitation deficits in vulnerable populations of wealthy countries may not be fully captured by JMP monitoring. For example, the data sources relied on by JMP may not accurately quantify these, including but not limited to: open defecation in populations experiencing homelessness [64], the rural poor in soil or geological conditions that make onsite wastewater solutions infeasible or unaffordable [65], and small communities with networked sewer that discharges to surface water without treatment [66–68].

Conclusions

We demonstrated the application of a single quantitative metric to describe progress on a multi-rung sanitation ladder and applied it to gap-filled JMP data in a retrospective analysis of sanitation progress from 1990–2015. Of the 190 countries (representing 99.8% of global population) in the analysis, 149 achieved greater progress on the Sanitation Ladder Score than on the binary Improved/Unimproved metric used under the MDGs. Using the progress categories established by JMP, 41 countries achieved a higher categorical progress on the ladder and five fell into a lower progress category. Countries with large gains in the population using shared sanitation tended to have substantially greater progress on the Sanitation Ladder Score. We propose that countries struggling with sanitation coverage under the SDGs might gain insight into possible approaches by looking to countries that made notable progress during the MDG period from varying baseline conditions. Thus, we presented data for six example countries, with insight from the literature into their particular approaches to increasing sanitation coverage and we provided relevant references for further reading. The use of a single quantitative metric to describe progress toward any development goal could be particularly useful for contexts in which there are multiple service level targets and/or changes in targets between global development regimes.

This Sanitation Ladder Score could be modified to incorporate the new "Safely Managed" service level tracked under the SDGs. Likewise, it could be modified to provide insight into Drinking Water, Hygiene, and other SDG targets. The authors hope that our database will provide other groups with the opportunity to conduct their own analyses; all data from this analysis are available in MS Excel format at melliott.people.ua.edu/data.html.

Supporting information

S1 Fig. A map of the countries discussed in the section "Country-level Progress". The six countries in dark green had pie-chart graphs showing country-level, urban and rural ladder coverage in 1990 and 2015 with a country-level discussion. The five countries in light green are mentioned in the subsequent subsection, "Additional countries of interest." Base map from naturalearthdata.com.
(DOCX)

Acknowledgments

Thanks to Aaron Blackwell for help with maps, Emily Elliott for help with figures, and to Alycia Overbo for sharing her experience on gap-filling to populate the sanitation database. We would like to acknowledge the previously published 'WatSan Cluster' methodology of Kyle Onda, Jonny Crocker, Georgia Kayser and Jamie Bartram used here. Finally, we would like to recognize the WHO/UNICEF Joint Monitoring Programme for their initiative and effort to monitor and make publicly available data on sanitation service levels even when those data were not required for assessing progress toward the current global development targets.

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