Research Paper

Household water treatment using adequate methods in sub-Saharan countries: evidence from 2013–2016 Demographic and Health Surveys

Abraham Geremew and Yohannes Tefera Damtew

ABSTRACT

In sub-Saharan countries, where a large number of populations depend on unsafe water, household water treatment is the recommended means to reduce diarrhea. However, the practice in the region is very low. The current study is intended to assess the households' water treatment using adequate methods, boiling, adding bleach, filtration and solar disinfection, and associated factors in the region which will be an input to design and implement intervention strategies. The Demographic and Health Survey (DHS) data conducted from 2013 to 2016 in 23 sub-Saharan countries were obtained from the DHS program and weighted using the 'svy' command for analysis. The households' reported use of treatment methods and associated factors were analyzed using log-binomial regression. In total, 357,979 households were included in the analysis of which 29% used unimproved water for drinking purposes. Households reportedly treating water in the region were 22% and those who used adequate treatment methods were 18%. The households' reported use of adequate treatment methods was statistically associated with household head education, owning a radio and wealth quintiles. The treatment methods' use is low in the region therefore intervention on wide-scale use should be designed and implemented.

Key words | adequate treatment methods, household water treatment

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INTRODUCTION

Globally, 663 million people depend on unimproved sources and about 2.1 billion use contaminated water (WHO/ UNICEF 2015). In addition, there is a range of studies that show post-collection contamination of water, despite their collection from improved sources (Bain *et al.* 2014; Shaheed *et al.* 2014). In sub-Saharan Africa, only 41% of the

population uses a water source that is free from contamination and only 24% use safely managed water sources (WHO/UNICEF 2017).

Diarrhea continues to be the leading cause of mortality and morbidity in the world with the highest share in the least developed countries (WHO/UNICEF 2015; Troeger *et al.* 2018). A recent study shows that it is the eighth leading cause of death for all age groups and the fifth leading cause in children below five years (Troeger *et al.* 2018). In sub-Saharan countries, where the disease burden is high, the proportion of morbidity in the age group of below five

years ranged from 10 to 35% (Bado *et al.* 2016). Lack of safe water is one of the leading risk factors for diarrhea to occur (Troeger *et al.* 2018).

Household water treatment coupled with safe storage can reduce the risk of diarrheal disease (WHO 2019). Water treatment at the household level can also minimize the risk of recontamination that even improved water supply can present (Wright *et al.* 2004). The household treatment methods recommended to be used are different chlorine-based disinfectants, filtration, solar disinfection, and boiling (Sobsey *et al.* 2008). These treatment methods are characterized as adequate based on their microbiological effectiveness (WHO & UNICEF 2006). Their effectiveness is acknowledged in some sub-Saharan countries (Crump *et al.* 2004, 2005; Mengistie *et al.* 2013; Mohamed *et al.* 2016; Bitew *et al.* 2018).

In regions like sub-Sahara, where the provision of improved water to all segments of the population is a challenge, the wide-scale use of the treatment methods at the household level is anticipated to reduce the burden of diarrhea associated with unsafe water use (Rosa & Clasen 2010). However, only a small number of households used it, and the consistency in use is dropping over time (Waddington *et al.* 2009; Brown & Clasen 2012). Only 18.2% of households in Africa treat water at the household level despite the fact that it is a region with the highest number of populations dependent on unimproved water sources (Rosa & Clasen 2010; WHO/UNICEF 2015).

Thus, in the region where nearly 60% of populations and about 24% of the population respectively use improved and safely managed drinking water sources (WHO/UNICEF 2015), facilitating households to use adequate water treatment methods is imperative to reduce the associated health problems. This can be ensured through identifying and addressing factors associated with use. In this regard, a few independent studies using Demographic and Health Survey (DHS) data were conducted to indicate the household treatment practices and associated factors (Wright & Gundry 2009; Geremew *et al.* 2018b). The current study is, therefore, intended to assess the households' reported use of adequate water treatment methods and associated factors using the DHS data in the region from 2013 to 2016. The findings would help policymakers and other stakeholders to design and implement appropriate strategies for wide-scale use of the treatment options.

METHODS

Data source

We used the data of DHS conducted between 2013 and 2016/17 in 23 countries. Namely, Angola, Benin, Burundi, Chad, Congo Democratic Republic, Ethiopia, Gambia, Ghana, Kenya, Lesotho, Liberia, Malawi, Mozambique, Namibia, Nigeria, Rwanda, Sierra Leone, South Africa, Togo, Tanzania, Uganda, Zambia, and Zimbabwe. DHS are nationally representative, cross-sectional household surveys (DHS 2009). Typically, around 5,000–30,000 households were sampled using a multilevel cluster survey design and mostly information was obtained by individuals' self-report (Corsi *et al.* 2012). The questionnaires are adapted for different settings but are comparable between countries (Footman *et al.* 2015). The data were obtained through online registration on the MEASURE DHS program.

Study variables

In the DHS, households were asked about water treatment practices at the household level using the statement 'Do you do anything to make water cleaner before drinking it?' Those households responded 'yes' to the question were asked about the type of treatment methods they reportedly used. The outcome of this study was, therefore, the households' reported use of adequate water treatment methods. The categorization of households into a reported user of adequate treatment methods or not is based on the response of households to the DHS questions 'What do you usually do to make the water safer to drink?' Households reportedly used either bleach, boiling, filtration and solar disinfection (SODIS) or all (WHO & UNICEF 2006) and were considered as a reported user of adequate treatment methods and non-user otherwise. Thus, households in each country reportedly using either or all of the mentioned treatment methods were considered a yes (1) and no otherwise (0 = if the household had used none of them).

Although the factors associated with the use of water, sanitation, and hygiene technologies are various, categorized into

contextual, psychosocial, and product-related (Dreibelbis *et al.* 2013), only contextual factors are available in the DHS data and these were considered for the current analysis. They are education status of household head, presence of children below five years in the house, owning radio and television, wealth categorized into five quintiles (poorest, poorer, middle, higher and highest), type of water source (improved versus unimproved), and residency (urban, rural). The data of associated factors were taken directly as they were in the DHS data set. The method of analysis for variables such as wealth quintiles was based on the PCA using the household assets as indicated elsewhere (Croft *et al.* 2018). We categorized some variables such as drinking water sources as improved and unimproved following the WHO/UNICEF guide (WHO & UNICEF 2006).

Data analysis

The 'svy' command in Stata 14.0 (Stata Corp, College Station, Texas, USA) was used to weight the survey data for the adjustment of cluster sampling design in the merged data set of 23 countries. The weighted data were analyzed descriptively using frequency and percentage. We used the prevalence ratio (log-binomial regression) to determine associated factors with households' reported water treatment as the odds ratio overestimates the factors when the outcome of interest exceeds 10% prevalence (in our case 18%) (Greenland 2004). Bivariate regression was applied to determine the unadjusted effects of each of the variables on household water treatment. We then subsequently included the variables for multivariable regression to assess the independent effect after controlling other variables. The significant association of predictor variables was considered at *p*-value <0.05. Multicollinearity diagnostic was conducted to check the interaction of factors and exclude using the variance inflation factor of greater than 10.

RESULTS

Household number and survey year

Table 1 indicates the number of households included in the survey and the survey year. The DHS survey year for Congo DR, the Gambia, Liberia, Namibia, Nigeria, Sierra Leone,

Table 1 | The number of households included in respective countries and survey year, DHS 2013–2016

Year of survey	Country	Number of households, n
2013	Congo (DR)	18,171
	Gambia	6,217
	Liberia	9,333
	Namibia	9,849
	Nigeria	38,522
	Sierra Leone	12,629
	Togo	9,549
	Zambia	15,920
2014	Chad	17,233
	Ghana	11,835
	Kenya	36,430
	Lesotho	9,402
	Rwanda	12,699
2015	Angola	16,109
	Malawi	26,361
	Mozambique	7,169
	Tanzania	12,563
	Zimbabwe	10,534
2016	Benin	14,156
	Burundi	15,977
	Ethiopia	16,650
	South-Africa	11,083
	Uganda	19,588
	Total	**357,979**

Togo, and Zambia was 2013. In Chad, Ghana, Kenya, Lesotho, and Rwanda, the survey was in 2014. Similarly, 2015 was the survey year for Angola, Malawi, Mozambique, Tanzania, and Zimbabwe. Lastly, 2016 was a survey year for Benin, Burundi, Ethiopia, South Africa, and Uganda.

Characteristics of households

Table 2 shows the characteristics of households surveyed in the region. More than 60% of households resided in rural areas, 45% of households owned a radio and 29% owned a television. More than a quarter of households of the 23 countries use unimproved drinking water sources and about one-fifth of the households walk for more than 30 minutes to collect water.

Household drinking water sources and treatment practices

Figure 1 shows the drinking water sources and water treatment practices. In total, 103,109 households (29%) used

Table 2 | The characteristics of households in sub-Saharan countries of pooled DHS data surveyed in 2013–2016

Characteristics	Category	Weighted frequency and percentage
Household head education status	No education	102,735 (28.92)
	Primary	126,848 (35.71)
	Secondary	96,289 (27.11)
	Higher	29,361 (8.27)
Residency of households	Urban	116,023 (37.47)
	Rural	193,652 (62.53)
Wealth status of households	Poorest	70,201 (19.61)
	Poorer	69,964 (19.54)
	Middle	69,912 (19.53)
	Higher	72,583 (20.28)
	Highest	75,320 (21.04)
Owned radio	No	162,952 (45.53)
	Yes	194,982 (54.47)
Owned television	No	253,590 (70.85)
	Yes	104,319 (29.15)
Water source type	Improved	254,782 (71.19)
	Unimproved	103,109 (28.81)
Water source distance	In the premises	69,156 (23.44)
	Within 30 minutes	165,58 (56.14)
	More than 30 minutes	56,236 (19.06)

unimproved water sources for drinking purposes. The number of households dependent on unimproved water sources ranged from 8% in South Africa to 51% in the Democratic Republic of the Congo. More than three-fifths of households that used improved water sources for drinking purposes and reportedly treated at household level were located in Kenya, Rwanda, Tanzania, and Uganda. Four countries where three-quarters of improved water source user households reportedly treated using adequate treatment methods were Angola, Kenya, Rwanda, and Uganda. In twelve countries, below one-tenth of households used improved water sources for drinking purpose and reportedly treated water at the household level. Of the twelve countries where the lowest number of households reported treated, the least number was shown in Benin and Burundi.

Household reported water treatment practices versus drinking water source

The highest number of households that depended on unimproved water and reportedly treated their water at household level was found in the Gambia (68.5%) and

Uganda (64.9%). The least number of households that depended on unimproved water sources and reportedly treated water was in the Democratic Republic of the Congo (1.7%). The adequate treatment methods use among households dependent on unimproved water sources was highest in Uganda followed by Kenya and Rwanda, and lowest in the Democratic Republic of the Congo (Table 3).

In total, 56,494 (22%) of households that used improved water sources reportedly treated their water and 48,019 (19%) of households reportedly treated using adequate treatment methods. Of unimproved water source users, 21,260 (21%) reportedly treated and 16,150 (16%) used adequate treatment methods. The overall reported use of treatment methods in the region was 22% and the reported use of adequate treatment methods was 18%. The reported use of adequate treatment use was higher in Kenya, Rwanda, and Uganda compared to others. Below one-tenths of households in twelve countries reportedly treated water at the household level with the lowest number in Benin (2.3%), the Gambia (2.7%) and Ghana (2.7%) (Table 3).

Type of treatment methods reportedly used

The types of treatment methods that the households reportedly used to treat water were boiling, bleach, filter, SODIS, let the water stand and settle, cloth straining, and other methods with the respective percentages of 10.81, 8.64, 0.79, 0.07, 1.25, 1.69, and 1.82%. Boiling shares the highest number (41%) with more than 50% of households reportedly treating water in each of seven countries (Burundi, Lesotho, Namibia, Nigeria, Tanzania, Togo, and Uganda). The highest number of the use of boiling occurred in Lesotho (87%), Uganda (82%), and Rwanda (80%). The lowest number occurred in Benin, Gambia, and Liberia. In nine countries (Angola, Chad, Congo, Liberia, Malawi Sierra Leone, Togo, Zambia, and Zimbabwe), more than half of households reportedly treated water using bleach. The high number of reported use of bleach was indicated in Liberia and the lowest was in Burundi. Of the adequate treatment methods, SODIS is reportedly used by a small number of households and is never used in three countries (Burundi, Lesotho, and Namibia). Let it stand and settle and cloth straining respectively ranked third and fourth for the households in the region (Figure 2).
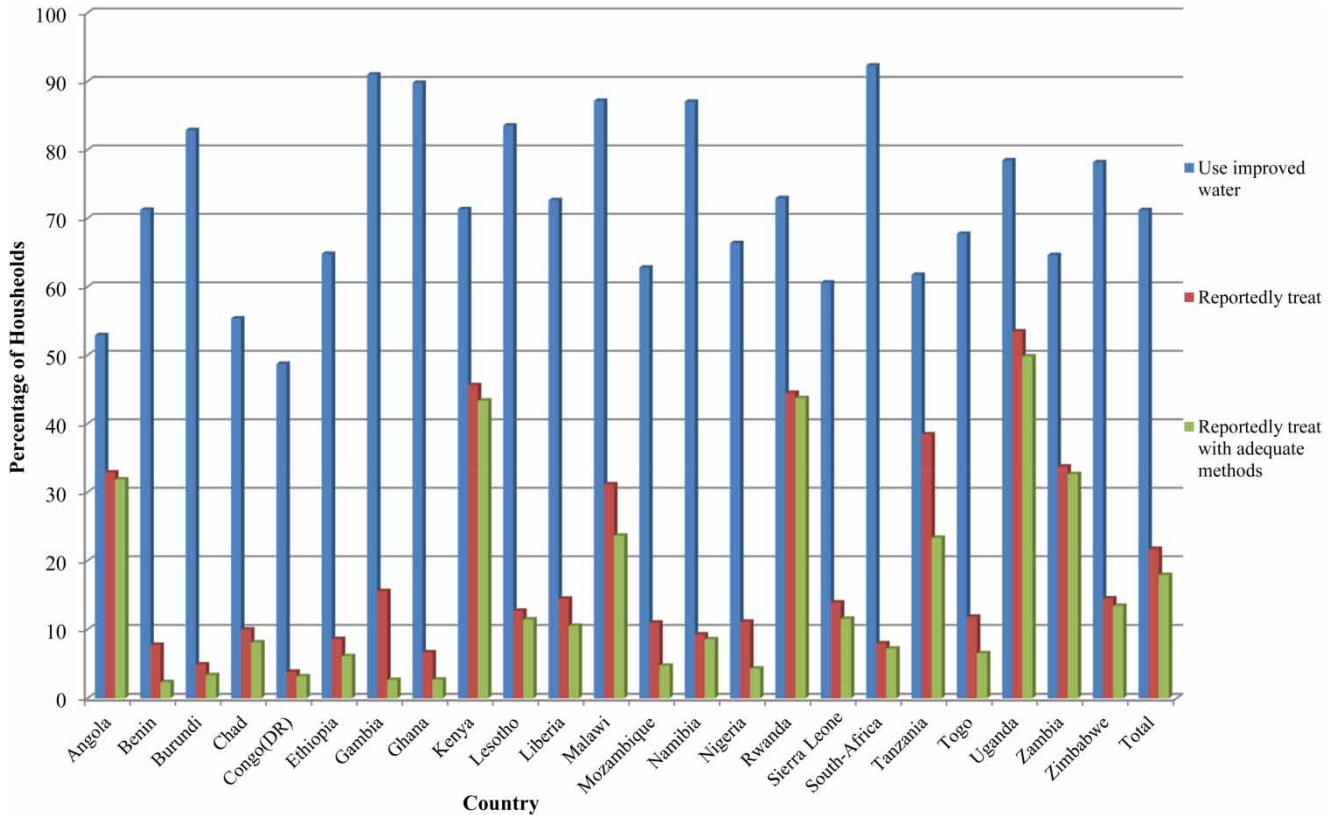
Figure 1 | Households using improved water sources and reportedly treating water at household level in sub-Saharan countries, DHS 2013–2016.

Factors associated with household water treatment using adequate treatment methods

The binary log-binomial regression shows that the proportion of households that used adequate treatment methods was higher among those households that owned a radio, a television, had an educated household head or were in the richer and richest wealth quintile. On the other hand, the ratio of adequate water treatment use between households that depend on improved and unimproved water sources did not vary significantly. In addition, there is no significant difference among households of having children under five years old and dwelling in urban or rural areas in the reported use of adequate treatment methods (Table 4).

The multivariable regression indicates that the proportion of households using adequate treatment methods to treat the water at the household level is significantly associated with owning a radio (ARR = 1.17, 95% CI = 1.01, 1.36). The number of households using adequate treatment methods in the richer and richest wealth quintiles is respectively 2.57 (95% CI = 1.77, 3.75) and 3.87 (95% CI = 2.19, 6.84) times higher compared to those households in the poorest wealth quintile (Table 4).

DISCUSSION

The overall reported water treatment at the household level in 23 countries was 22% and the reported water treatment using adequate methods was 18%. Based on the water sources that households depend on, 22 and 21% respectively were the number of improved and unimproved water source users reportedly treating water. Our finding was inconsistent with a prior study that shows that about 29% of households dependent on an improved water source and 27% of households dependent on unimproved water sources reportedly treat their drinking water at the household level (Rosa & Clasen 2010). The reported use of water treatment methods in the region is low despite the preponderance of diarrhea

Table 3 | Household drinking water sources versus treatment practices in sub-Saharan countries based on DHS 2013–2016

| | Household water treatment practice | | | |
| | Among improved water source | | Among unimproved water source | |
Country	Reportedly treat, *n* (%)	Reportedly used adequate method, *n* (%)	Reportedly treat, *n* (%)	Reportedly used adequate method, *n* (%)
Angola	3,289 (38.57)	3,188 (37.39)	2,008 (26.48)	1,944 (25.64)
Benin	495 (4.91)	111 (1.10)	604 (14.83)	221 (5.43)
Burundi	645 (4.87)	463 (3.50)	139 (5.07)	73 (2.66)
Chad	1,078 (11.32)	915 (9.61)	640 (8.34)	483 (6.30)
Congo (DR)	546 (6.17)	467 (5.27)	155 (1.67)	112 (1.20)
Ethiopia	819 (7.59)	653 (6.05)	613 (10.46)	365 (6.24)
Gambia	582 (10.32)	125 (2.20)	384 (68.54)	42 (7.48)
Ghana	603 (5.68)	286 (2.69)	185 (15.30)	36 (2.98)
Kenya	11,974 (46.09)	11,455 (44.09)	4,651 (44.54)	4,347 (41.62)
Lesotho	1,020 (12.99)	966 (12.29)	174 (11.26)	111 (7.21)
Liberia	1,127 (16.62)	854 (12.59)	224 (8.76)	128 (5.00)
Malawi	7,048 (30.67)	5,330 (23.20)	1,164 (34.38)	908 (26.82)
Mozambique	627 (13.94)	253 (5.63)	159 (5.98)	86 (3.22)
Namibia	719 (8.40)	668 (7.80)	193 (15.10)	176 (13.79)
Nigeria	2,594 (10.14)	1,356 (5.30)	1,684 (13.00)	313 (2.41)
Rwanda	4,391 (47.42)	4,324 (46.70)	1,260 (36.68)	1,231 (35.84)
Sierra Leone	1,471 (19.21)	1,267 (16.55)	286 (5.74)	190 (3.82)
South-Africa	801 (7.83)	727 (7.11)	84 (9.83)	73 (8.52)
Tanzania	3,243 (41.81)	2,051 (26.43)	1,585 (32.98)	884(18.41)
Togo	645 (9.98)	445 (6.88)	484 (15.75)	180 (5.85)
Uganda	7,779 (50.62)	7,281 (47.38)	2,695 (63.87)	2,483 (58.86)
Zambia	3,857 (37.54)	3,748 (36.48)	1,503 (26.77)	1,436 (25.56)
Zimbabwe	1,141 (13.85)	1,088 (13.21)	388 (16.87)	327 (14.21)
Total	**56,493 (22.18)**	**48,019 (18. 85)**	**21,260 (20.62)**	**16,150 (15.66)**

associated with water safety (Troeger *et al.* 2018). The overall reported use would have been higher to reduce the burden that could be from unimproved water sources, post-collection contamination and the presence of pathogens, even in improved water sources (Bain *et al.* 2014; Shaheed *et al.* 2014).

The use of adequate treatment methods did not differ significantly among households living in urban and rural areas although households in the rural area mostly depend on unimproved water sources. The current results did not corroborate a prior study that shows caregivers dwelling in urban areas were more likely to treat their water than those in a rural dwelling (Geremew *et al.* 2018a).

The treatment methods use was lower among households with a non-educated household head, in the poorest wealth quintile that did not own a radio where the suffering from diarrhea is highly likely. The finding complies with two independent studies of DHS data that show household water treatment is high among households with an educated household head and high wealth quintiles (Wright & Gundry 2009; Geremew *et al.* 2018b).

The reported water treatment did not differ considerably between households using improved and unimproved water sources and unimproved sources. This could be from a low perception about the quality of unimproved water as prior findings indicate that households perceived poor water quality
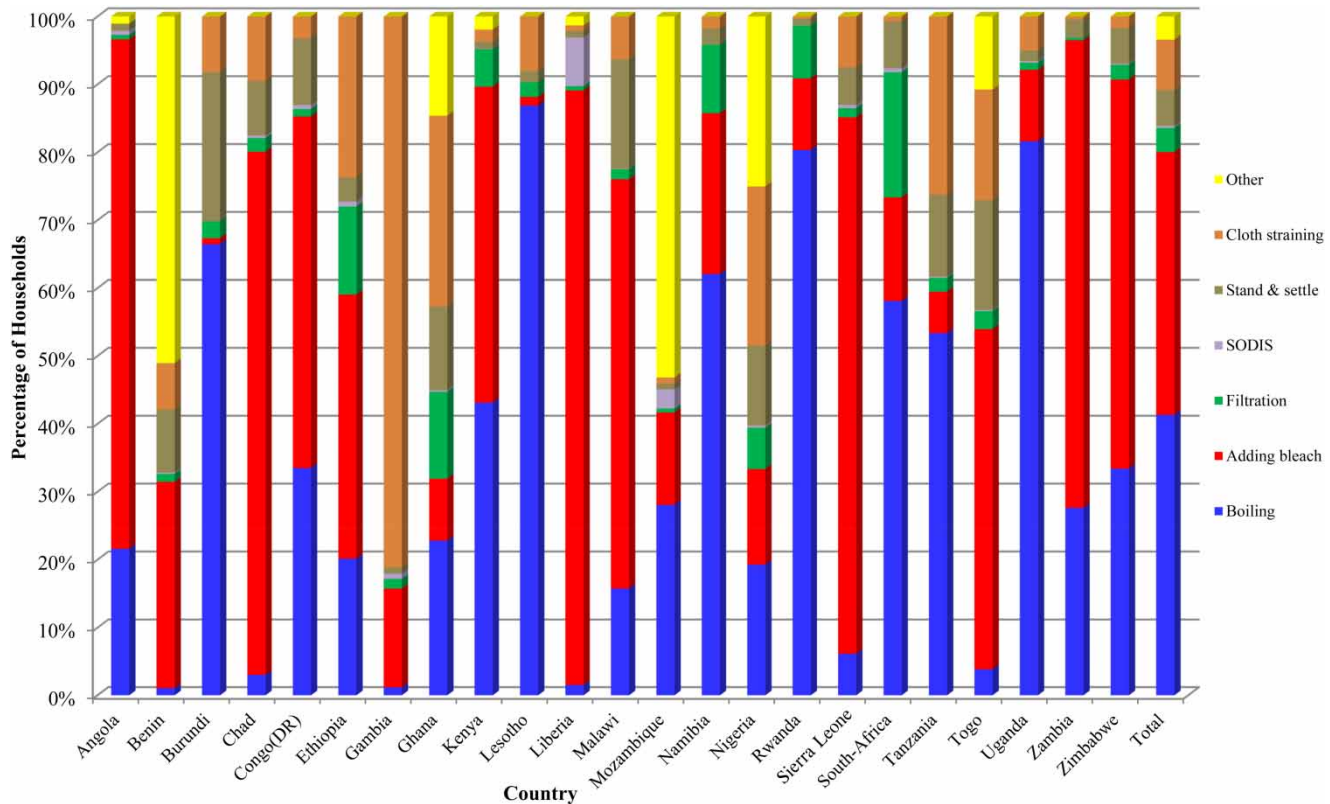
Figure 2 │ Type of treatment methods reportedly used by households in sub-Saharan countries, DHS 2013–2016.

was more likely to treat (Jain *et al.* 2014; Onjala *et al.* 2014). In addition, the household reported that the use of adequate treatment methods did not differ among households that had or had no children below the age of five years, despite evidence that diarrheal disease associated with unsafe water in this age group is high (Troeger *et al.* 2018). The results suggest much work is needed to improve the accessibility of products and behavior interventions for wide-scale use of treatment methods in the region (Figueroa & Kincaid 2010).

The number of households reportedly treating water varies from country to country. Those countries with more than 30% of households reportedly treating water with adequate treatment methods were Angola, Ghana, Nigeria, Togo, and Zambia. Less than one-tenth of households reportedly treat water with adequate treatment methods in twelve countries. When we compare our findings with prior findings on thirteen countries included in the survey, there was a slight increment (Rosa & Clasen 2010).

The reported use of boiling, bleach, filter, and SODIS respectively is 10.81, 8.64, 0.79 and 0.07% despite their

reliability and effectiveness as indicated in prior studies (Clasen 2009; Clasen *et al.* 2015). The current finding also implies that support and promotion by NGOs, international agencies and governments are still remaining (Clasen *et al.* 2007, 2015). The overall use of adequate treatment methods is higher than a prior report in 22 African countries based on the number of populations that show that 10.6% treat their drinking water at the household level (Rosa & Clasen 2010).

Boiling is a more predominant treatment method with over 41% of households overall reportedly using it. It is commonly used in ten countries and more than 80% of households used boiling in Lesotho, Rwanda, and Uganda. A small number of households reportedly used boiling compared to bleach in Benin, Gambia, and Liberia with only about 1% of households compared to other countries. The preference for boiling compared with other methods complies with prior assessments in some African countries that show that many prefer to use traditional methods, including boiling rather than chemical methods (PATH 2010). In

Table 4 | The binary and multivariable log-binomial regression on factors associated with household water treatment using adequate treatment methods in sub-Saharan countries, DHS 2013–2016

Characteristics	Category	Households use adequate treatment methods, *n* (%)		CRR, 95% CI	ARR, 95% CI
		No	Yes		
Owned radio	No[a]	141,735	21,217	1	1
	Yes	152,025	42,958	1.66 (1.37, 2.01)	1.17 (1.01, 1.36)
Owned television	No[a]	215,000	38,589	1	1
	Yes	78,743	25,575	1.62 (1.07, 2.44)	0.81 (0.55, 1.20)
Household wealth quintile	Poorest[a]	64,076	6,125	1	1
	Poorer	60,829	9,135	1.47 (1.22, 1.77)	1.40 (1.16, 1.69)
	Middle	58,224	11,688	1.91 (1.43, 2.55)	1.86 (1.37, 2.53)
	Richer	57,297	15,285	2.51 (1.80, 3.48)	2.57 (1.77, 3.75)
	Richest	53,371	21,949	3.59 (2.53, 5.10)	3.87 (2.19, 6.84)
House head education status	No[a]	94,178	8,557	1	1
	Primary	100,877	25,970	2.32 (1.86, 2.89)	2.02 (1.55, 2.63)
	Secondary	76,563	19,726	2.34 (1.59, 3.43)	1.78 (1.28, 2.47)
	Higher	20,104	9,257	3.74 (2.68, 5.20)	2.20 (1.56, 3.10)
Household residency	Urban[a]	87,235	28,788	1	1
	Rural	159,705	33,947	0.69 (0.47, 1.00)	1.14 (0.80, 1.61)
Children presence in the house	No[a]	133,647	29,921	1	1
	Yes	160,150	34,262	0.98 (0.86, 1.10)	1.10 (0.97, 1.24)
Water source type	Improved[a]	206,763	48,019	1	1
	Unimproved	86,959	16,150	0.86 (0.68, 1.10)	1.31 (0.99, 1.75)

[a]CRR = Crude risk ratio, ARR = adjusted risk ratio, CI = confidence interval.

addition, the common use of boiling compared to other adequate treatment options in the region is consistent with previous findings (Rosa & Clasen 2010). The number of households reportedly using bleach as a treatment method accounts for 38% of reportedly treating water. The overall use of the products is about 8% which makes it the second highest next to boiling. Of the 23 countries, 13 were reportedly predominant users of bleach compared to others including boiling. In total, a small number of households' reported use could be because of different factors, mainly taste, accessibility and affordability as indicated elsewhere (Olembo *et al.* 2004; Luby *et al.* 2008; DuBois *et al.* 2010).

SODIS is the least popular treatment method, reportedly used by only 0.3% of households despite preceding studies that reported that SODIS is effective in reducing diarrhea in children (Asiimwe *et al.* 2013; Bitew *et al.* 2018). The three countries where SODIS is not reportedly used were Burundi, Lesotho, and Namibia. Of the countries reportedly using SODIS, Liberia is the country with the highest number

of reported users. The small number of households reporting the use of SODIS in the region suggests the need for appropriate intervention methods like household promotion in combination with persuasion which was found to be effective in changing the behavior of households to use the treatment in Zimbabwe (Mosler *et al.* 2013).

STRENGTHS AND LIMITATIONS

The current study has the following strengths: (1) The survey in each country is conducted every five years by taking representative samples, hence, the representativeness of the data is high. In addition, analysis of data after pooling would show the situation of household water treatment practices in the region. The limitations of the study are: (1) We used survey data which is liable to biases and the factors and outcomes fail to show cause and effect relationships. (2) The current findings could not show the actual use of products as it was a self-reported use. (3) Only contextual

factors were available in the DHS dataset, therefore it did not comprehensively show all potential factors.

CONCLUSIONS

Below one-fifth of households reportedly treat their water using adequate treatment methods in the region. Boiling and adding bleach are the predominant methods compared to others. The reported use of treatment methods is high among households with educated household heads, which owned a radio, and were in high wealth quintiles. Interventions that take into account the context of the countries should be designed and implemented for wide-scale use of treatment methods.

ETHICS APPROVAL

We followed the principles and procedures of the MEASURE DHS Program. Each of the surveys was conducted after ethical clearance was obtained from the appropriate Ethics Review Committee of the country.

AVAILABILITY OF DATA

The datasets used and/or analyzed during the current study belong to the DHS program.

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REFERENCES

Asiimwe, J., Quilty, B., Muyanja, C. & McGuigan, K. 2013 Field comparison of solar water disinfection (SODIS) efficacy between glass and polyethylene terephalate (PET) plastic bottles under sub-Saharan weather conditions. *J. Water Health* **11** (4), 729–737.

Bado, A. R., Susuman, A. S. & Nebie, E. I. 2016 Trends and risk factors for childhood diarrhea in sub-Saharan countries (1990–2013): assessing the neighborhood inequalities. *Glob. Health Action* **9** (1), 30166.

Bain, R., Cronk, R., Wright, J., Yang, H., Slaymaker, T. & Bartram, J. 2014 Fecal contamination of drinking-water in low-and middle-income countries: a systematic review and meta-analysis. *PLoS Med.* **11** (5), e1001644.

Bitew, B. D., Gete, Y. K., Biks, G. A. & Adafrie, T. T. 2018 The effect of SODIS water treatment intervention at the household level in reducing diarrheal incidence among children under 5 years of age: a cluster randomized controlled trial in Dabat district, northwest Ethiopia. *Trials* **19** (1), 412.

Brown, J. & Clasen, T. 2012 High adherence is necessary to realize health gains from water quality interventions. *PLoS One* **7** (5), e36735.

Clasen, T. 2009 *Scaling up Household Water Treatment among Low-Income Populations*. World Health Organization, Geneva.

Clasen, T., Schmidt, W.-P., Rabie, T., Roberts, I. & Cairncross, S. 2007 Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *Br. Med. J.* **334** (7597), 782.

Clasen, T. F., Alexander, K. T., Sinclair, D., Boisson, S., Peletz, R., Chang, H. H., Majorin, F. & Cairncross, S. 2015 Interventions to improve water quality for preventing diarrhoea. *Cochrane Database Syst. Rev.* **10**, 1–180.

Corsi, D. J., Neuman, M., Finlay, J. E. & Subramanian, S. 2012 Demographic and Health Surveys: a profile. *Int. J. Epidemiol.* **41** (6), 1602–1613.

Croft, T. N., Marshall, A. M. & Allen, C. K. 2018 *Guide to DHS Statistics*. ICF, Rockville, Maryland, USA.

Crump, J., Okoth, G., Slutsker, L., Ogaja, D., Keswick, B. & Luby, S. 2004 Effect of pointof-use disinfection, flocculation and combined flocculation–disinfection on drinking water quality in western Kenya. *J. Appl. Microbiol.* **97**, 225–231.

Crump, J. A., Otieno, P. O., Slutsker, L., Keswick, B. H., Rosen, D. H., Hoekstra, R. M., Vulule, J. M. & Luby, S. P. 2005 Household based treatment of drinking water with flocculant-disinfectant for preventing diarrhoea in areas with turbid source water in rural western Kenya: cluster randomised controlled trial. *Br. Med. J.* **331** (7515), 478.

DHS 2009 *Demographic and Health Surveys, Quality Information to Plan, Monitor, and Improve Population, Health, and Nutrition Programs© 2008 Erberto Zani, Courtesy of Photoshare*. MEASURE DHS, The DHS Program. Available from: https://dhsprogram.com/Who-We-Are/…/MEASURE_DHS_Brochure.pdf (cited 8/12/2019).

Dreibelbis, R., Winch, P. J., Leontsini, E., Hulland, K. R., Ram, P. K., Unicomb, L. & Luby, S. P. 2013 The integrated behavioural model for water, sanitation, and hygiene: a systematic review of behavioural models and a framework for designing and evaluating behaviour change interventions in infrastructure-restricted settings. *BMC Public Health* **13** (1), 1015.

DuBois, A. E., Crump, J. A., Keswick, B. H., Slutsker, L., Quick, R. E., Vulule, J. M. & Luby, S. P. 2010 Determinants of use of

household-level water chlorination products in rural Kenya, 2003–2005. *Int. J. Environ. Res. Public Health* **7** (10), 3842–3852.

Figueroa, M. E. & Kincaid, D. L. 2010 *Social, Cultural and Behavioral Correlates of Household Water Treatment and Storage. HCenter Publication HCI 2010-1: Health Communication Insights.* Johns Hopkins Bloomberg School of Public Health, Center for Communication Programs, Baltimore.

Footman, K., Benova, L., Goodman, C., Macleod, D., Lynch, C., Penn-Kekana, L. & Campbell, O. 2015 Using multi-country household surveys to understand who provides reproductive and maternal health services in low-and middle-income countries: a critical appraisal of the Demographic and Health Surveys. *Trop. Med. Int. Health* **20** (5), 589–606.

Geremew, A., Mengistie, B., Alemayehu, E., Lantagne, D. S., Mellor, J. & Sahilu, G. 2018a Point-of-use water chlorination among urban and rural households with under-five year children: a comparative study in Kersa Health and Demographic Surveillance Site, Eastern Ethiopia. *J. Water Sanit. Hyg. Dev.* **8** (3), 468–480.

Geremew, A., Mengistie, B., Mellor, J., Lantagne, D. S., Alemayehu, E. & Sahilum, G. 2018b Appropriate household water treatment methods in Ethiopia: household use and associated factors based on 2005, 2011, and 2016 EDHS data. *Environ. Health Prevent. Med.* **23** (1), 46.

Greenland, S. 2004 Model-based estimation of relative risks and other epidemiologic measures in studies of common outcomes and in case-control studies. *Am. J. Epidemiol.* **160** (4), 301–305.

Jain, M., Lim, Y., Arce-Nazario, J. A. & Uriarte, M. 2014 Perceptional and socio-demographic factors associated with household drinking water management strategies in rural Puerto Rico. *PLoS One* **9** (2), e88059.

Luby, S. P., Mendoza, C., Keswick, B. H., Chiller, T. M. & Hoekstra, R. M. 2008 Difficulties in bringing point-of-use water treatment to scale in rural Guatemala. *Am. J. Trop. Med. Hyg.* **78** (3), 382–387.

Mengistie, B., Berhane, Y. & Worku, A. 2013 Household water chlorination reduces incidence of diarrhea among under-five children in rural Ethiopia: a cluster randomized controlled trial. *PLoS One* **8** (10), e77887.

Mohamed, H., Clasen, T., Njee, R. M., Malebo, H. M., Mbuligwe, S. & Brown, J. 2016 Microbiological effectiveness of household water treatment technologies under field use conditions in rural Tanzania. *Trop. Med. Int. Health* **21** (1), 33–40.

Mosler, H., Kraemer, S. & Johnston, R. 2013 Achieving long-term use of solar water disinfection in Zimbabwe. *Public Health* **127** (1), 92–98.

Olembo, L., Kaona, F., Tuba, M. & Burnham, G. 2004 *Safe Water Systems: An Evaluation of the Zambia CLORIN Program (Final Report).* Zambia. Available from: http: www.ehproject.

org/pdf/others/zambia%20report%20format.pdf (cited 8/12/2019).

Onjala, J., Ndiritu, S. W. & Stage, J. 2014 Risk perception, choice of drinking water and water treatment: evidence from Kenyan towns. *J. Water Sanit. Hyg. Dev.* **4** (2), 268–280.

PATH 2010 *Market Assessment of Household Water Treatment Products in Eight African Countries, Project Brief.* Program for Appropriate Technology in Health (PATH), Seattle, Washington, DC, USA.

Rosa, G. & Clasen, T. 2010 Estimating the scope of household water treatment in low-and medium-income countries. *Am. J. Trop. Med. Hyg.* **82** (2), 289–300.

Shaheed, A., Orgill, J., Ratana, C., Montgomery, M. A., Jeuland, M. A. & Brown, J. 2014 Water quality risks of 'improved' water sources: evidence from Cambodia. *Trop. Med. Int. Health* **19** (2), 186–194.

Sobsey, M. D., Stauber, C. E., Casanova, L. M., Brown, J. M. & Elliott, M. A. 2008 Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world. *Environ. Sci. Technol.* **42** (12), 4261–4267.

Troeger, C., Blacker, B. F., Khalil, I. A., Rao, P. C., Cao, S., Zimsen, S. R., Albertson, S. B., Stanaway, J. D., Deshpande, A. & Abebe, Z. 2018 Estimates of the global, regional, and national morbidity, mortality, and aetiologies of diarrhoea in 195 countries: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet Infect. Dis.* **18** (11), 1211–1228.

Waddington, H., Snilstveit, B., White, H. & Fewtrell, L. 2009 Water, sanitation and hygiene interventions to combat childhood diarrhoea in developing countries. *Sythn. Rev.* **1**, 17–22.

WHO 2019 *Results of Round II of the WHO International Scheme to Evaluate Household Water Treatment Technologies.* Licence: CC BY-NC-SA 3.0 IGO. World Health Organization, Geneva.

WHO & UNICEF 2006 *Core Questions on Drinking Water and SANITATIOn for Household Surveys.* Available from: https://apps.who.int/iris/handle/10665/43489 (cited 7/3/2019).

WHO/UNICEF 2015 *Joint Monitoring Programme for Water Supply and Sanitation (JMP) (2015).* Available from: www.unicef.org/publications/index_82419.html (cited 12/5/2016).

WHO/UNICEF 2017 Safely managed services: Accounting for service levels. *Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines* (A. Grojec, ed.). World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), Geneva, Switzerland.

Wright, J. & Gundry, S. W. 2009 Household characteristics associated with home water treatment: an analysis of the Egyptian Demographic and Health Survey. *J. Water Health* **7** (1), 21–29.

Wright, J., Gundry, S. & Conroy, R. 2004 Household drinking water in developing countries: a systematic review of microbiological contamination between source and point of use. *Trop. Med. Int. Health* **9** (1), 106–117.