Title

Exploring the link between handwashing proxy measures and child diarrhea in 25 countries in sub-Saharan Africa: a cross-sectional study

Journal

Journal of Water Sanitation and Hygiene for Development, 7(2)

ISSN

2043-9083

Authors

Hirai, Mitsuaki
Roess, Amira
Huang, Cheng
et al.

Publication Date

2017-06-01

DOI

10.2166/washdev.2017.126

Peer reviewed

Exploring the link between handwashing proxy measures and child diarrhea in 25 countries in sub-Saharan Africa: a cross-sectional study

Mitsuaki Hirai, Amira Roess, Cheng Huang and Jay P. Graham

ABSTRACT

Handwashing (HW) with soap is considered the most cost-effective intervention for reducing the risk of child diarrhea, but reliable measurement of HW behaviors is difficult. This study examined the association between proxy HW measures and child diarrhea by analyzing nationally representative household survey data from 25 countries in sub-Saharan Africa ($n = 212,492$). The main explanatory variable was the HW ladder, representing a varying level of availability of HW materials in the household, and the outcome variable was a 2-week prevalence of child diarrhea. We estimated the prevalence ratio of child diarrhea between children with a basic HW station and without a HW place. Our analysis revealed that availability of water and soap at a HW place was associated with both increased and decreased prevalence ratios: 0.89 (95% CI 0.79–0.99) in Chad, 0.82 (0.69–0.97) in Mauritania, 1.30 (1.02–1.66) in Burkina Faso, and 1.67 (1.20–2.33) in Ghana. After controlling for country-fixed effects, the prevalence ratio was 0.95 (0.92–0.99), suggesting a protective effect of having a HW station with water and soap. Availability of HW resources is an important indicator to prevent child diarrhea, and HW promotion programs should be tailored to the unique context of each country.

Key words | child health, diarrhea, handwashing, hygiene

Mitsuaki Hirai (corresponding author)
Amira Roess
Cheng Huang
Jay P. Graham
Milken Institute School of Public Health, Department of Global Health,
The George Washington University,
950 New Hampshire Ave., Suite 400,
Washington,
DC 20052,
USA
E-mail: *mhirai@gwu.edu*

INTRODUCTION

Diarrhea remains one of the leading causes of under-five mortality and disproportionately affects low-income countries and regions (Walker *et al.* 2013; Liu *et al.* 2015). In 2012, 361,000 children lost their lives to diarrhea globally, and 44% of this mortality occurred in sub-Saharan Africa (Prüss-Ustün *et al.* 2014). Inadequate access to safe drinking water, basic sanitation, and hygiene practice is estimated to account for 58% of diarrheal deaths (World Health Organization [WHO] 2014). Diarrhea prevention through water, sanitation, and hygiene interventions is therefore of vital importance to facilitate the well-being of each child.

Handwashing (HW) with soap has been estimated to reduce the risk of diarrhea by 23%–48% (Fewtrell *et al.* 2005; Cairncross *et al.* 2010; Freeman *et al.* 2014), and hygiene promotion is recognized as a cost-effective public health intervention to avert disease burden (Bartram & Cairncross 2010). However, the proportion of the global population who practice HW with soap is very low. The estimated prevalence of HW with soap after using the toilet or contacting excreta is 19% globally, and it is lowest in sub-Saharan Africa at 14% (Freeman *et al.* 2014). Empirical evidence from 11 countries also suggested that rates of HW with soap at other critical moments including before feeding and before cooking are also low, and HW is often performed with water only (Curtis *et al.* 2009). To promote HW with soap more effectively, previous research examined what drives people's HW behaviors and developed a few conceptual models to explain how HW habits can be formed

doi: 10.2166/washdev.2017.126

(Coombes & Devine 2010; Dreibelbis *et al.* 2013; Contzen & Mosler 2015).

HW with soap may be shaped or facilitated by addressing its determinants, including social norms, motivations, and habits (Curtis *et al.* 2011), but accurate measurement of this behavior remains difficult. While HW can be efficiently measured by self-reports, people tend to overestimate their behaviors (Manun'Ebo *et al.* 1997; Biran *et al.* 2008). Alternative measures of HW behaviors include *proxy measures*, such as observing the availability of HW materials in the household and testing microbiological contamination of hands, and *direct measures*, such as structured observations and video observations (Ram 2013). Of these measurement approaches, rapid observations of HW resources have been implemented in large household surveys, such as the Demographic and Health Survey (DHS) and the Multiple Indicator Cluster Survey (MICS) as an efficient and objective measure (Ram 2013).

Although the presence of HW materials in the household does not provide information on frequency and timings of HW behaviors, this proxy measure can be useful to monitor the progress in improving access to HW facilities. The Joint Monitoring Programme (JMP) for Water Supply and Sanitation by the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) has proposed to monitor 'percentage of population with hand washing facilities with soap and water at home' under the Sustainable Development Goals framework (WHO/UNICEF 2015a). DHS and MICS now include these indicators and will likely continue monitoring these HW indicators throughout the Sustainable Development Goals. A HW ladder that uses these indicators has also been proposed with three rungs: (1) no HW facility present; (2) HW facility present without water or soap; and (3) HW facility present with water and soap (WHO/UNICEF 2015b).

Global monitoring efforts to assess the availability of water and soap in the household for HW creates opportunities to test how HW proxy measures from large household surveys are associated with child diarrhea. Initial work has been conducted in five countries in sub-Saharan Africa and shows mixed results; the HW proxy was not associated with child diarrhea in Ethiopia and Ghana but associated with it in Malawi, Sierra Leone, and Zimbabwe (Shelus & Hernandez 2015). Our study builds on this previous work by expanding the geographic scope to 25 countries in sub-Saharan Africa with the most recent DHS and MICS datasets and developing a HW ladder, which indicates a progressive improvement in access to water and soap at the HW place in the household. Our objective was to examine if a newly developed HW ladder is associated with the 2-week prevalence of child diarrhea in each country and the region as a whole. We hypothesized that a negative association exists between the presence of water and soap in the household and child diarrhea after controlling for potential confounders.

METHODS

Data source and samples

This study used data from DHS and MICS conducted from 2010 to 2014 in 25 sub-Saharan African countries. The DHS Program began in 1984 as a collaborative program between the United States Agency for International Development and low- and middle-income countries to collect nationally representative household data on many health-related indicators (Corsi *et al.* 2012). Another large household survey, MICS, has been conducted by UNICEF since 1995 to facilitate global efforts to improve the lives of children and women (UNICEF 2014). DHS and MICS select nationally representative survey respondents by employing a stratified two-stage cluster sampling design (ICF International 2012). Each country is typically stratified by type of residence (urban or rural) and each sub-country region (ICF International 2012). In the first stage, a sample of enumeration areas or clusters (e.g., village, a city block) are randomly selected from each stratum, and in the second stage, households are systematically selected from clusters (ICF International 2012). A team of trained interviewers subsequently visit selected households for data collection. Data for children under five years of age are then collected from mothers (aged 15–49) who participated in the survey, and more than one child from the same household could be included (ICF International 2012). The list of DHS/MICS countries and the total number of eligible children under five years included in this study are summarized in Table 1. After deleting observations

Table 1 | DHS and MICS included in this study

Country	Dataset/Rounds	Year	Regions	Total number of children (<5 years)	% included (*n*)
Benin	DHS/VI	2011–2012	WA	12,615	82.7 (10,432)
Burkina Faso	DHS/VI	2010	WA	13,583	78.9 (10,718)
Burundi	DHS/VI	2010	EA	7,184	94.1 (6,760)
CAF	MICS/4	2010	CA	10,474	88.1 (9,232)
Chad	MICS/4	2010	CA	17,006	73.0 (12,412)
Comoros	DHS/VI	2012	EA	3,007	87.2 (2,622)
DRC	DHS/VI	2013–2014	CA	16,999	90.3 (15,347)
Cote d'Ivoire	DHS/VI	2011–2012	WA	6,941	77.8 (5,403)
Ethiopia	DHS/VI	2011	EA	10,556	96.0 (10,133)
Gambia	DHS/VI	2013	WA	7,682	94.6 (7,268)
Ghana	DHS/VII	2014	WA	5,471	89.1 (4,875)
Guinea	DHS/VI	2012	WA	6,331	77.8 (4,928)
Malawi	MICS/5	2013–2014	EA	18,981	93.4 (17,729)
Mali	DHS/VI	2012–2013	WA	9,557	90.4 (8,638)
Mauritania	MICS/4	2011	WA	9,278	71.1 (6,601)
Mozambique	DHS/VI	2011	EA	10,154	95.0 (9,644)
Namibia	DHS/VI	2013	SA	4,688	85.4 (4,003)
Nigeria	DHS/VI	2013	WA	28,358	70.1 (19,879)
Senegal	DHS/VII	2014	WA	6,554	89.6 (5,872)
Sierra Leone	DHS/VI	2013	WA	10,573	82.6 (8,731)
Swaziland	MICS/4	2010	SA	2,647	82.7 (2,188)
Togo	DHS/VI	2013–2014	WA	6,405	78.0 (4,996)
Uganda	DHS/VI	2011	EA	7,208	80.4 (5,795)
Zambia	DHS/VI	2013–2014	EA	12,410	74.2 (9,203)
Zimbabwe	MICS/5	2014	EA	9,884	96.0 (9,489)
Sub-Saharan Africa region	DHS/MICS	2011–2014	SSA	254,546	83.5 (212,492)

CA = Central Africa; EA = Eastern Africa; SA = Southern Africa; WA = Western Africa.

without complete information (i.e., listwise deletion), the proportion of eligible children included in the analysis was 83%, ranging from 70.1% in Nigeria to 96.0% in Ethiopia and Zimbabwe.

Variables

The main independent variable for this study was the HW ladder, representing four conditions of a HW place in the household. During the data collection, the presence of a HW location in the household was initially observed (1 = observed, 2 = not observed [not in dwelling/yard/plot], 3 = not observed, no permission, 4 = not observed, other reason). If a HW location was observed, the availability of water (1 = water is available, 2 = water is unavailable) and types of cleansing supplies were subsequently assessed through direct observations. These directly observed indicators were combined into a single variable to show a varying level of availability of HW materials in the household. In this study, *soap* included bar or liquid soap, detergent, and locally available materials (e.g., ash, mud). The proposed hygiene ladder included the following measures: (1) absence of a HW place in the household (none); (2) presence of a HW place only; (3) presence of a HW place with water or soap (incomplete); and (4) presence of a HW place with water and soap (basic).

Other independent variables included type of drinking water source, type of sanitation facility, household wealth quintile, water collection time (0 = taking less than 30 minutes, 1 = taking 30 minutes or longer for a round trip), and maternal education (0 = no formal education, 1 = primary education, 2 = secondary education or higher, 3 = religious schools [only in Mauritania]). The drinking water source and sanitation facilities were categorized as the water ladder (1 = surface water, 2 = unimproved sources, 3 = improved sources, 4 = piped water on premise) and the sanitation ladder (0 = open defecation, 1 = unimproved, 2 = improved but shared, 3 = improved) as defined by JMP (UNICEF/WHO 2015). DHS and MICS include the wealth index in each dataset, but this index has been constructed with types of drinking water sources and sanitation facilities (Rutstein & Johnson 2004). To exclude water and sanitation variables as part of the wealth measurement, a new wealth quintile was constructed with 14 types of household assets – electricity, radio, TV, refrigerator, bicycle, motorcycle, car, phone, cell phone, bank account, floor materials, wall materials, roof materials, and cooking fuel – by conducting principal component analysis. Initially, wealth indices were developed separately for urban and rural residents to account for different implications of household assets in respective areas, and they were merged as a national wealth index. This study used the 2-week prevalence of child diarrhea as the dependent variable (0 = No, 1 = Yes). The control variables for the multivariate analysis were child sex, child age, month of data collection, sub-country regions, number of household members, number of household rooms, and urban/rural residence.

Statistical analysis

Bivariate analyses were conducted to examine the association between the proposed HW ladder and child diarrhea in each country by the chi-square test. Multivariate analyses were performed for each country using generalized linear model with Poisson family and log link functions to estimate the prevalence ratio of child diarrhea as a more interpretable ratio estimate than odds ratio (Barros & Hirakata 2003). All of the categorical independent variables were analyzed with an appropriate STATA command (i.e., i.group). To address multicollinearity, if the variance inflation factor was higher than 5 for any independent variable, it was removed from the multivariate model. All the analysis was adjusted for the complex survey design of DHS and MICS for the country level analysis (ICF International 2012).

This study also combined datasets from 25 countries to examine how the hygiene ladder was associated with child diarrhea in the sub-Saharan Africa region as a whole and by sub-populations, such as children in Western Africa, Central Africa, and Southern Africa. The pooled analysis clustered standard errors by primary sampling units of each country. Sampling weights in DHS and MICS only allow inferences at the country level but not at the regional level (e.g., sub-Saharan Africa). Each survey was conducted in different years, and existing sampling weights do not account for diverse population characteristics between countries. Thus, the pooled analysis may not benefit from applying country-specific sampling weights. For these reasons, the results of the pooled analysis are presented as unweighted with robust variances. The equations of multivariate regression models for each country and the sub-Saharan Africa region are presented in the Supplementary material.

RESULTS

A total of 212,492 children under five years of age were included in this analysis, ranging from 2,188 in Swaziland to 19,879 in Nigeria (Table 1). Over 20% of children in six countries (Burundi, Central African Republic, Chad, Malawi, Senegal, Uganda) had diarrhea in the last 2 weeks prior to data collection while the prevalence was less than 10% in Benin and Mali (Table 2). The proportion of children who do not have access to a HW place in the household (HW ladder 1) was greater than 50% in 15 countries, and it was highest in Ethiopia at 98.5%. In five countries (Chad, Ghana, Mauritania, Namibia, Swaziland), over 20% of children had access to a HW place with water and soap (HW ladder 4), but the overall proportion remained low.

The two-week prevalence of child diarrhea by each component of the HW ladder is illustrated in Figure 1. The diarrhea prevalence was consistently higher than 20% across the HW ladder in Burundi, Chad, Malawi, and

Table 2 | Two-week prevalence of child diarrhea and distribution of the HW ladder (%)

Country	Diarrhea (% of children)	No HW place (% of children)	HW place only (% of children)	Incomplete (% of children)	Basic (% of children)
Benin	6.52	64.48	16.06	10.00	9.46
Burkina Faso	15.50	7.46	44.54	37.84	10.16
Burundi	25.24	5.50	75.95	12.39	6.15
CAF	23.56	78.07	1.69	3.68	16.55
Chad	24.23	43.80	10.60	20.20	25.40
Comoros	16.35	44.79	13.17	23.31	18.73
DRC	16.69	84.51	8.13	4.11	3.24
Cote d'Ivoire	18.22	40.70	29.01	16.36	13.93
Ethiopia	13.55	98.49	0.45	0.58	0.47
Gambia	17.67	93.48	1.44	2.18	2.91
Ghana	11.56	44.22	21.84	13.63	20.30
Guinea	15.32	56.69	18.21	16.67	8.44
Malawi	24.25	90.13	1.87	4.39	3.61
Mali	8.69	74.62	7.52	8.30	9.56
Mauritania	16.48	38.19	9.55	19.06	33.21
Mozambique	11.33	54.31	21.34	11.01	13.34
Namibia	18.85	10.67	20.23	24.92	44.18
Nigeria	10.43	48.62	26.85	12.29	12.25
Senegal	20.03	73.16	7.28	6.19	13.36
Sierra Leone	11.85	77.21	12.55	3.78	6.46
Swaziland	16.47	24.81	22.78	26.27	26.15
Togo	15.30	82.76	3.50	4.32	9.42
Uganda	23.48	67.78	13.94	10.16	8.12
Zambia	16.39	54.13	17.58	15.14	13.14
Zimbabwe	15.51	84.31	1.86	6.30	7.53
Sub-Saharan Africa region	16.38	62.04	14.85	11.15	11.96

HW, handwashing; Incomplete, water or soap is present at the HW place; Basic, both water and soap are present at the HW place.

Uganda, and there was not a clear trend of reductions in the diarrhea prevalence by comparing a lower HW ladder (i.e., no HW place) with a higher HW ladder (i.e., HW place with water and soap). One exception was Namibia where the diarrhea prevalence progressively declined by moving up the hygiene ladder from no HW place (26.06%), HW place only (20.71%), HW place with water or soap (19.23%), to HW place with water and soap (16.05%). Additional figures on the two-week prevalence of child diarrhea (Figure S1), the proportion of children without a household HW place (Figure S2), and the proportion of children with access to a HW place with water and soap (Figure S3) are available as supplementary materials.

In 12 countries (Benin, Burkina Faso, Comoros, DRC, Cote d'Ivoire, Ghana, Guinea, Mauritania, Mozambique, Senegal, Sierra Leone, Swaziland), children whose household had access to a place for HW with water and soap (HW ladder 4) had higher diarrhea prevalence than those children in households without a place for HW (HW ladder 1). Yet, the difference of diarrhea prevalence was small (Table S1). There was a significant association between the HW ladder and child diarrhea ($p < 0.05$) in

Table 3 | Pooled prevalence ratio of child diarrhea by HW ladders in sub-populations

Sub-population groups	HW place only	Incomplete	Basic
Sub-Saharan Africa region ($n = 212,492$)	1.04 (1.01, 1.08)*	1.05 (1.01, 1.08)*	0.95 (0.92, 0.99)**
Western Africa ($n = 98,190$)	1.05 (1.00, 1.10)	1.06 (1.00, 1.13)*	0.99 (0.94, 1.05)
Eastern Africa ($n = 71,269$)	1.10 (1.03, 1.17)**	1.07 (1.01, 1.15)*	0.95 (0.88, 1.02)
Central Africa ($n = 36,948$)	0.98 (0.89, 1.07)	1.01 (0.93, 1.09)	0.91 (0.85, 0.97)**
Southern Africa ($n = 6,085$)	0.88 (0.72, 1.07)	0.83 (0.69, 1.00)*	0.78 (0.65, 0.93)**
Male children ($n = 107,014$)	1.05 (1.00, 1.11)*	1.06 (1.00, 1.11)*	0.94 (0.90, 0.99)*
Female children ($n = 105,478$)	1.04 (0.99, 1.09)	1.03 (0.98, 1.09)	0.96 (0.91, 1.01)
Urban residence ($n = 60,774$)	1.09 (1.02, 1.17)*	1.01 (0.95, 1.08)	0.93 (0.88, 0.99)*
Rural residence ($n = 151,718$)	1.03 (0.99, 1.07)	1.07 (1.02, 1.12)**	0.99 (0.94, 1.04)

The model only adjusted for country and year fixed effects.
*$p < 0.05$ **$p < 0.01$.

seven countries (Benin, Mozambique, Namibia, Nigeria, Senegal, Togo, Zimbabwe).

The results of country-level multivariate analyses are presented in Figure 2. In most of the countries, there was not a significant difference in diarrhea prevalence between children living in households that had a HW place with water and soap (HW ladder 4) and those living in households without a HW place (HW ladder 1). The direction and strength of association between the HW ladder and child diarrhea also differed by countries after controlling for confounders. For example, in Chad and Mauritania, having a basic HW station in the household was associated with 11% and 18% lower prevalence of child diarrhea ($p < 0.05$) while it was associated with 30% and 67% higher prevalence in Burkina Faso and Ghana ($p < 0.01$).

Pooled data analysis

After pooling datasets and controlling for the country-fixed effects, diarrhea prevalence among children who had access to a HW place with water and soap (HW ladder 4) was 5% lower than that of children without a HW place (HW ladder 1) in sub-Saharan Africa ($p < 0.05$). However, the presence of a HW place without (HW ladder 2) or with limited HW materials (HW ladder 3) was associated with 5% higher diarrhea prevalence than that of children without a HW place. A significant protective effect of having a basic HW station was found among males and children in Central Africa, Southern Africa, and urban areas. The largest protective effect was found in Southern Africa where the presence of water and soap at a HW place was associated with a 22% lower prevalence of child diarrhea, compared to that of children without any HW place in the household ($p < 0.05$).

By controlling for sociodemographic factors and country-fixed effects, the diarrhea prevalence among children with a HW station with water and soap was no longer significantly different from that of children without a HW place in the household (Table 4). Having a HW place without or limited HW materials, however, was associated with 5% ($p < 0.05$) and 7% ($p < 0.001$) higher diarrhea prevalence, respectively. Water and sanitation ladders were also significantly associated with child diarrhea. Compared to children who rely on surface water (e.g., pond, dam, lake) as their drinking water source, the diarrhea prevalence of children who had access to piped water on premise was 12% lower ($p < 0.001$). Improved sanitation was associated with a 14% lower prevalence of diarrhea than that of children from families who practiced open defecation ($p < 0.001$). Accordingly, water and sanitation ladders are useful to demonstrate the health benefits of climbing up the ladders while the HW ladder does not present similar empirical evidence. A water collection time of 30 minutes or less was also associated with a 7% lower diarrhea prevalence than that of children whose families take over 30 minutes to collect their drinking water ($p < 0.001$).

Children's biological sex, age, type of residence, and maternal education were also significantly associated with

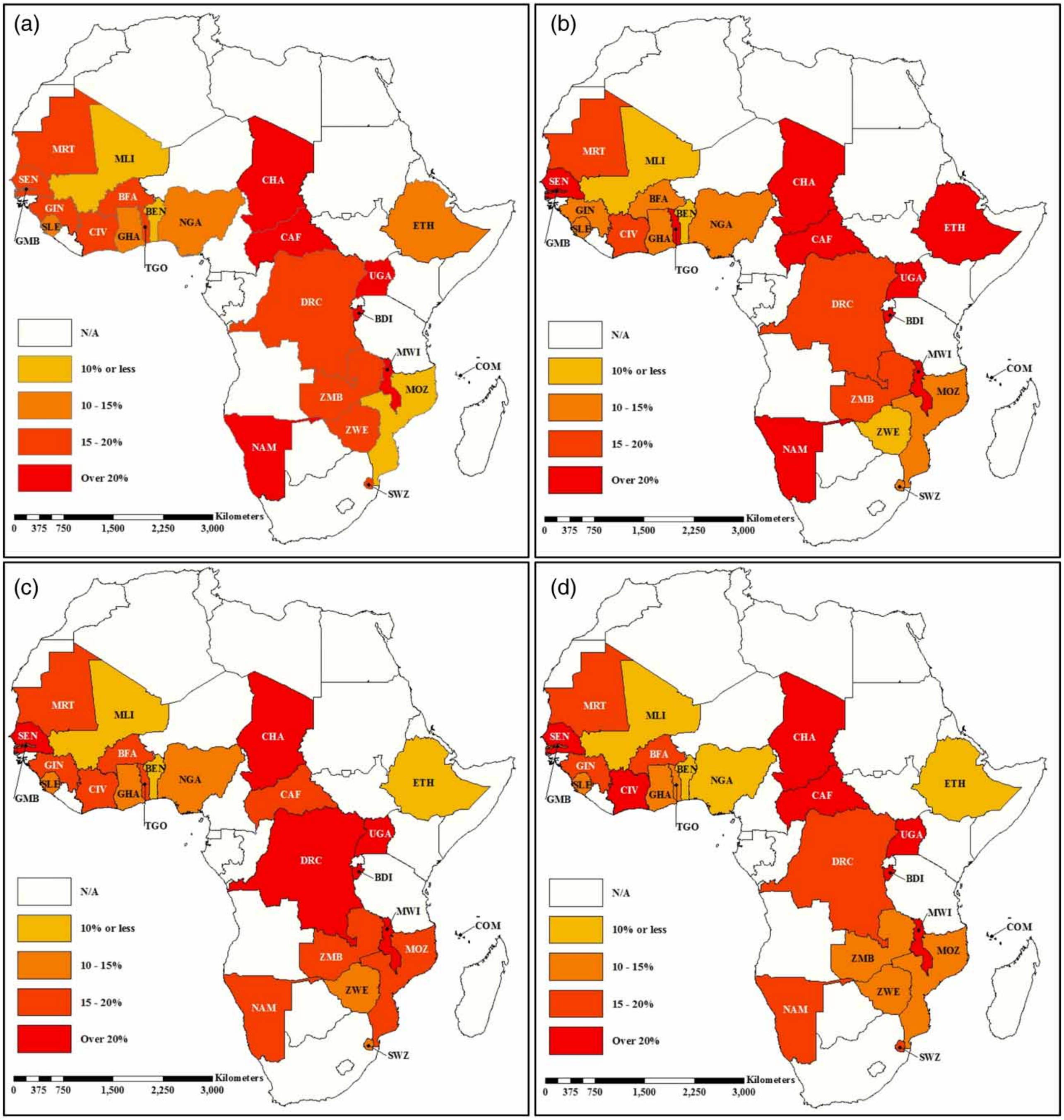

Figure 1 | Two-week prevalence of child diarrhea by the HW ladder: (a) no HW place; (b) HW place only; (c) HW place with water or soap; (d) HW place with water and soap.

child diarrhea. More specifically, female children had a 6% lower diarrhea prevalence than male children ($p < 0.001$). Compared to infants, children who were 1 year old (12–23 months) had 39% higher diarrhea prevalence ($p < 0.001$). The diarrhea prevalence of children whose mothers received at least some secondary education or higher was 8% ($p < 0.01$) lower than that of children whose mothers had no education. However, maternal education of at least some primary education was associated with a 5% higher prevalence of child diarrhea ($p < 0.001$), so incomplete

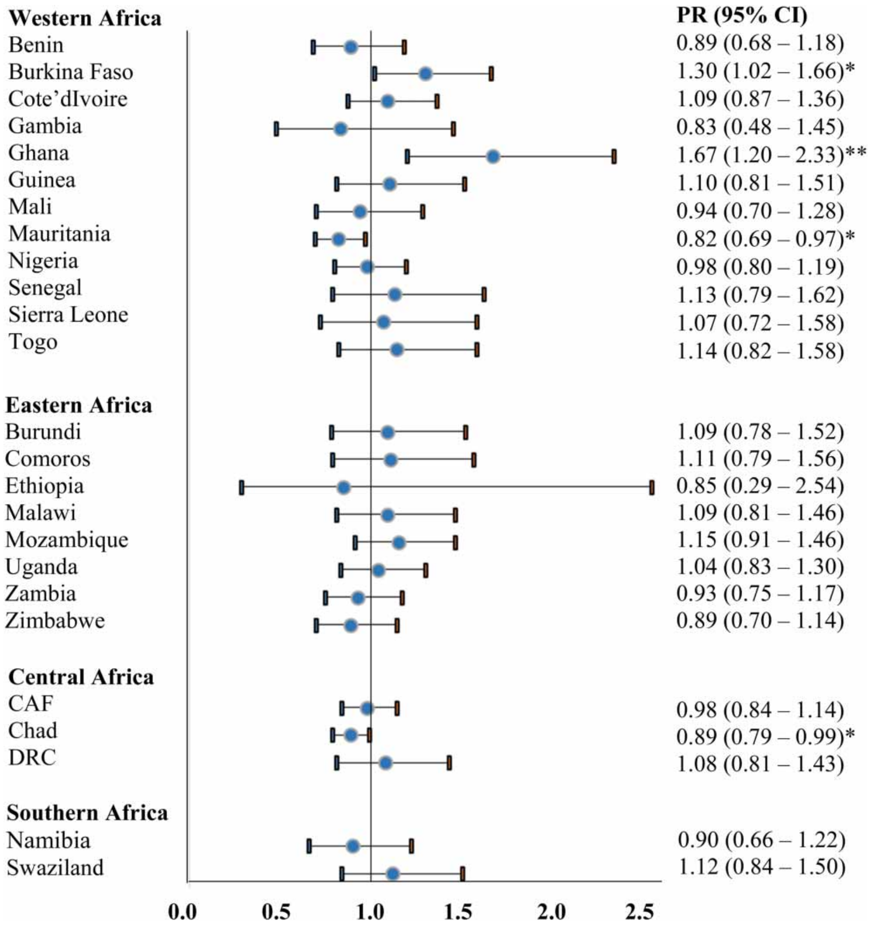

Figure 2 | Adjusted prevalence ratios of child diarrhea comparing children who do not have a HW place and children who have access to a HW place with water and soap. $*p < 0.05$ $**p < 0.01$; CAF = Central African Republic; DRC = Congo Democratic Republic.

primary education did not provide protective effects for child diarrhea. A statistically significant difference was not found between urban and rural residents.

DISCUSSION

This study examined if HW proxy measures in large household surveys were associated with child diarrhea in 25 countries in sub-Saharan Africa. The analysis revealed that the HW ladder was not associated with child diarrhea in most of the countries. This finding is in accordance with other studies in SSA that reported a limited or lack of association between HW proxy measures and child health outcomes (Kamm *et al.* 2014; Shelus & Hernandez 2015). As with previous research (Fink *et al.* 2011), water and sanitation ladders were found to be significantly associated with child diarrhea.

A varying level of strength and direction of association between the HW ladder and child diarrhea in 25 countries also highlighted the need for exploring unique contextual factors (e.g., norms, traditions) in each country to explain the findings. Our pooled data analysis controlled for such country-specific effects and suggested that the presence of HW stations with water and soap was associated with modest reductions in the prevalence of child diarrhea in sub-Saharan Africa as hypothesized. The sub-population analysis found a protective effect of having a HW station with water and soap in the Central Africa and Southern Africa regions but not in West Africa and East Africa regions. This finding suggests that sub-region fixed effects may exist to influence the association between the hygiene ladder and child diarrhea.

Table 4 | Adjusted prevalence ratio of child diarrhea by HW ladders and covariates ($n = 212,492$)

Variables	Prevalence ratio (95% CI)
HW ladder (Ref: No HW place)	
HW place only	1.05 (1.01, 1.08)*
HW place with water or soap	1.07 (1.03, 1.11)***
HW place with water and soap	1.01 (0.97, 1.05)
Water ladder (Ref: surface water)	
Unimproved	0.94 (0.90, 0.98)**
Other improved	0.93 (0.89, 0.96)***
Piped water on premise	0.88 (0.84, 0.93)***
Water collection time of 30 minutes or less (Ref: >30 min)	0.93 (0.91, 0.95)***
Sanitation ladder (Ref: open defecation)	
Unimproved	0.95 (0.92, 0.98)**
Shared	0.98 (0.94, 1.02)
Improved	0.86 (0.83, 0.89)***
Female children	0.94 (0.92, 0.96)***
Child age (Ref: <12 months)	
12–23 months	1.39 (1.35, 1.43)***
24–35 months	0.95 (0.92, 0.98)**
36–47 months	0.60 (0.57, 0.62)***
to 59 months	0.45 (0.43, 0.47)***
Rural residence (Ref: urban)	0.98 (0.95, 1.01)
Maternal education (Ref: no formal education)	
Primary	1.05 (1.03, 1.08)***
Secondary or higher	0.92 (0.89, 0.95)***
Religious school (only in Mauritania)	1.11 (0.97, 1.27)
Number of household members	1.01 (1.00, 1.01)***
Number of sleeping rooms	0.99 (0.99, 1.00)*

The model controlled for country fixed-effects and the month of data collection.
*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$.

In the pooled multivariate analysis, the diarrhea prevalence of children who have access to a HW place without or with limited HW materials was found to be significantly higher than that of children without a HW station in the household. While the exact reason for this finding remains unclear, children without a HW station may be washing their hands in ways that may not be captured by the survey. In Zimbabwe, for example, a large proportion of households have been reported to pour water from a small container for HW without having a defined location for HW (Zimbabwe National Statistics Agency 2015). Accordingly, the cultural norm or custom of HW behaviors largely vary between countries, and it could alter the relationship between the HW ladder and child diarrhea.

Another critical issue is that regardless of the availability of water and soap, children under the age of five are not likely to wash their hands by themselves. An observational study in rural Zimbabwe reported that infants and young children under 18 months old did not wash their hands with soap except for the time of bathing (Ngure *et al.* 2013). The same study also suggested that infants frequently put their potentially contaminated hands in their mouth, and a few infants were practicing geoghagy, or eating soil (Ngure *et al.* 2013). Other studies in Bangladesh and Kenya also reported the practice of geophagy by infants or young children as a risk factor of negative child health outcomes (Shivoga & Moturi 2009; George *et al.* 2015). Thus, the presence of water and soap at home may not block every possible pathway of the fecal–oral transmission of disease.

The results of the multivariate analyses, however, do not negate the importance of promoting access to HW facilities. Although the availability of water and soap may not always translate into HW with soap, physical facilities serve as an important behavioral cue and influence people's planning, habits, and motivations for HW behaviors (Curtis *et al.* 2009). In western Kenya, the presence of soap for HW was found to be associated with a reduced risk of child diarrhea (Kamm *et al.* 2014). Empirical research in Bangladesh also suggested that older residents of the household can contribute to reducing the risk of child diarrhea through their HW practices at critical moments, such as before cooking and after defecation (Luby *et al.* 2011). The presence of a HW station with water and soap in the household therefore can facilitate older household members' HW behaviors and contribute to protecting child health.

This study included a number of notable limitations. First, this study could not examine key behavioral indicators, such as frequency, timing, and HW materials used, due to limited data availability. While the HW ladder contributed to assessing the availability of HW resources, this study could not confirm if and how people washed their hands. Second, this study cannot establish the temporality of the hygiene ladder and child diarrhea. Observing severe diarrhea episodes of children could have compelled some households to create a HW station for disease prevention purposes. In this case, our hypothesized relationship between independent and dependent variables needs to be reversed. Third, this study conducted a complete case analysis by performing the listwise deletion, and the proportion of eligible children included in this study was 83% on average. Although we eliminated systematic missing (e.g., skipping patterns in the questionnaire) to the best extent possible, missing data may reduce the reliability of the findings. Fourth, this study presented an estimate of prevalence ratio of child diarrhea for the sub-Saharan African region and sub-regions. The analysis, however, did not include all of the countries in the region or sub-regions. Accordingly, the findings of this study need to be carefully interpreted. Fifth, this study might not fully control for the effects of dry and rain seasons by using the month of data collection as a proxy measure. Lastly, the pooled multivariate analysis did not include the wealth index, which represents the relative wealth levels of a household within each country (Rutstein & Johnson 2004). The use of country-specific wealth index for pooled analysis was therefore not the best indicator of relative wealth levels of households in the region. Nonetheless, we tested the model with the wealth quintile, which did not alter the strength and direction of association between the HW ladder and child diarrhea.

CONCLUSIONS

The present study examined the association between the HW proxy measure and child diarrhea in 25 countries in sub-Saharan Africa by using DHS and MICS. Despite the limitations identified, this study found a protective effect associated with having a HW station with water and soap on child diarrhea. Future studies should examine which factors are associated with the presence of a HW place with water and soap in low- and middle-income countries. Some preliminary work has already been conducted in the recent review of HW proxy measurement in DHS and MICS, exploring the proportion of households with a HW station with water and soap by household heads' educational attainment, household wealth levels, and type of residence (Loughnan *et al.* 2015). Collecting reliable and valid measurements of HW behaviors at a large scale is a very difficult undertaking. The HW proxy measure collected in large household surveys, however, is an important first step for monitoring and promoting HW with soap globally.

Additional studies could provide further insights into which factors facilitate the adoption of HW stations in the household. DHS and MICS also allow future research to examine the progress of increasing access to HW facilities over time in low- and middle-income countries. By using empirical evidence collected from nationally representative household surveys, HW with soap can be effectively promoted worldwide.

REFERENCES

Barros, A. J. D. & Hirakata, V. N. 2003 Alternatives for logistic regression in cross-sectional studies: an empirical comparison of models that directly estimate the prevalence ratio. *BMC Med. Res. Methodol.* **3** (Suppl 1), 21.

Bartram, J. & Cairncross, S. 2010 Hygiene, sanitation, and water: forgotten foundations of health. *PLoS Med.* **7** (11), e1000367.

Biran, A., Rabie, T., Schmidt, W., Juvekar, S., Hirve, S. & Curtis, V. 2008 Comparing the performance of indicators of handwashing practices in rural Indian households. *Trop. Med. Int. Health* **13**, 278–285.

Cairncross, S., Hunt, C., Boisson, S., Bostoen, K., Curtis, V., Fung, I. C. & Schmidt, W. P. 2010 Water, sanitation and hygiene for the prevention of diarrhoea. *Int. J. Epidemiol.* **39**, i193–i205.

Contzen, N. & Mosler, H. J. 2015 Identifying the psychological determinants of handwashing: results from two cross-sectional questionnaire studies in Haiti and Ethiopia. *Am. J. Infect. Control* **43** (8), 826–832.

Coombes, Y. & Devine, J. 2010 *Introducing FOAM: A Framework to Analyze Handwashing Behaviors to Design Effective Handwashing Programs*. World Bank, Water and Sanitation Program, Washington, DC.

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

Curtis, V., Danquah, L. & Aunger, R. 2009 Planned, motivated and habitual hygiene behavior: an eleven country review. *Health Educ. Res.* **24**, 655–673.

Curtis, V., Schmidt, W., Luby, S., Florez, R., Touré, O. & Biran, A. 2011 Hygiene: new hopes, new horizons. *Lancet Infect. Dis.* **11** (4), 312–321.

Dreibelbis, R., Winch, P. J., Leontsini, E., Hulland, K. R. S., 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.

Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L. & Colford, J. M. 2005 Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *Lancet Infect. Dis.* **5**, 42–52.

Fink, G., Günther, I. & Hill, K. 2011 The effect of water and sanitation on child health: evidence from the demographic and health surveys 1986–2007. *Int. J. Epidemiol.* **40** (5), 1196–1204.

Freeman, M. C., Stocks, M. E., Cumming, O., Jeandron, A., Higgins, J. P., Wolf, J., Prüss-Ustün, A., Bonjour, S., Hunter, P. R., Fewtrell, L. & Curtis, V. 2014 Hygiene and health: systematic review of handwashing practices worldwide and update of health effects. *Trop. Med. Int. Health* **19** (8), 906–916.

George, C. M., Oldja, L., Biswas, S., Perin, J., Lee, G. O., Kosek, M., Sack, R. B., Ahmed, S., Haque, R., Parvin, T., Azmi, I. J., Bhuyian, S. I., Talukder, K. A., Mohammad, S. & Faruque, A. G. 2015 Geophagy is associated with environmental enteropathy and stunting in children in rural Bangladesh. *Am. J. Trop. Med. Hyg.* **92** (6), 1117–1124.

ICF International 2012 *Demographic and Health Survey Sampling and Household Listing Manual*. ICF International, Calverton, MD, USA.

Kamm, K. B., Feikin, D. R., Bigogo, G. M., Aol, G., Audi, A., Cohen, A. L., Shah, M. M., Yu, J., Breiman, R. F. & Ram, P. K. 2014 Associations between presence of handwashing stations and soap in the home and diarrhoea and respiratory illness, in children less than five years old in rural western Kenya. *Trop. Med. Int. Health* **19** (4), 396–406.

Liu, L., Oza, S., Hogan, D., Perin, J., Rudan, I., Lawn, J. E., Cousens, S., Mathers, C. & Black, R. E. 2015 Global, regional, and national causes of child mortality in 2000–13, with projections to inform post-2015 priorities: an updated systematic analysis. *Lancet* **385**, 430–440.

Loughnan, L. C., Ram, P. K. & Luyendijk, R. 2015 Measurement of handwashing behavior in Multiple Indicator Cluster Surveys and Demographic and Health Surveys, 1985–2008. *Waterlines* **34** (4), 296–313.

Luby, S. P., Halder, A. K., Huda, T., Unicomb, L. & Johnston, R. B. 2011 The effect of handwashing at recommended times with water alone and with soap on child diarrhea in rural Bangladesh: an observational study. *Plos Med* **8** (6), e1001052.

Manun'Ebo, M., Cousens, S., Haggerty, P., Kalengaie, M., Ashworth, A. & Kirkwood, B. 1997 Measuring hygiene practices: a comparison of questionnaires with direct observation in rural Zaire. *Trop. Med. Int. Health* **2**, 1015–1021.

Ngure, F. M., Humphrey, J. H., Mbuya, M. N. N., Majo, F., Mutasa, K., Govha, M., Mazarura, E., Chasekwa, B., Prendergast, A. J., Curtis, V., Boor, K. J. & Stoltzfus, R. J. 2013 Formative research on hygiene behaviors and geophagy among infants and young children and implications of exposure to fecal bacteria. *Am. J. Trop. Med. Hyg.* **89** (4), 709–716.

Prüss-Ustün, A., Bartram, J., Clasen, T., Colford, J. M., Cumming, O., Curtis, V., Bonjour, S., Dangour, A. D., De France, J., Fewtrell, L., Freeman, M. C., Gordon, B., Hunter, P. R., Johnston, R. B., Mathers, C., Mäusezahl, D., Medlicott, K., Neira, M., Stocks, M., Wolf, J. & Cairncross, S. 2014 Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries. *Trop. Med. Int. Health* **19** (8), 894–905.

Ram, P. 2013 *Practical Guidance for Measuring Handwashing Behavior: 2013 Update*. World Bank, Water and Sanitation Program, Washington, DC.

Rutstein, S. O. & Johnson, K. 2004 *DHS Comparative Reports No. 6: The DHS Wealth Index*. ORC Macro, Calverton, MD, USA.

Shelus, V. & Hernandez, O. L. 2015 The usefulness of a handwashing proxy in large household surveys. *J. Water Sanit. Hyg. Dev.* **5** (4), 565–573.

Shivoga, W. A. & Moturi, W. N. 2009 Geophagia as a risk factor for diarrhoea. *J. Infect. Dev. Ctries.* **3** (2), 94–98.

UNICEF 2014 *Multiple Indicator Cluster Survey (MICS)*. Retrieved from http://www.unicef.org/statistics/index_24302.html (accessed 15 December 2015).

UNICEF/WHO 2015 *Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment*. World Health Organization, Geneva, Switzerland.

Walker, C. L. F., Rudan, I., Liu, L., Nair, H., Theodoratou, E., Bhutta, Z. A., O'Brien, K. L., Campbell, H. & Black, R. E. 2013 Global burden of childhood pneumonia and diarrhoea. *Lancet* **381**, 1405–1416.

WHO 2014 *Preventing Diarrhoea Through Better Water, Sanitation and Hygiene: Exposures and Impacts in low- and Middle-Income Countries*. World Health Organization, Geneva, Switzerland.

WHO/UNICEF 2015a *Methodological Note: proposed Indicator Framework for Monitoring SDG Targets on Drinking-Water, Sanitation, Hygiene and Wastewater*. Retrieved from http://www.wssinfo.org/fileadmin/user_upload/resources/Methodological-note-on-monitoring-SDG-targets-for-WASH-and-wastewater_WHO-UNICEF_8October2015_Final.pdf (accessed 14 December 2015).

WHO/UNICEF 2015b *WASH Post-2015: Proposed Indicators for Drinking Water, Sanitation and Hygiene*. Retrieved from http://www.who.int/water_sanitation_health/monitoring/coverage/wash-post-2015-rev.pdf?ua=1 (accessed 14 December 2015).

Zimbabwe National Statistics Agency 2015 Zimbabwe Multiple Indicator Cluster Survey 2014, Final Report. Harare, Zimbabwe.

First received 30 August 2016; accepted in revised form 11 February 2017. Available online 17 March 2017