Water, Sanitation, and Hygiene (WASH) for Child Health: Evidence from Large Household Surveys in Indonesia and Sub-Saharan Africa

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Evidence from Household Survey Data

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Dedication

The author wishes to dedicate this dissertation to children and their families who bear a great deal of disease burden from limited access to safe drinking water, adequate sanitation, and hand hygiene.

Acknowledgment

The author wishes to acknowledge all the time and support given by his dissertation committee members and readers, Dr. Sarah Baird and Dr. Rochelle Rainey, for the completion of his dissertation research. This research would not have been completed without their dedication. The author also would like to express the deepest gratitude to his mentor in life, Dr. Daisaku Ikeda, for his continuous encouragement to live a contributive life. Furthermore, the author is grateful for his family and friends for their care and support throughout his doctoral study at the George Washington University.

Abstract of Dissertation

Water, Sanitation, and Hygiene (WASH) for Child Health:
Evidence from Large Household Surveys in Indonesia and Sub-Saharan Africa

Background: Water, sanitation, and hygiene (WASH) are essential components of basic human necessities. The overall purpose of this dissertation was to inform where and how future WASH interventions could be conducted by analyzing household-level data from Indonesia and Sub-Saharan African countries.

Methods: The dissertation research adopted a three-paper model and conducted cross-sectional data analyses. The first study explored the potential determinants of handwashing with soap in Indonesia by using UNICEF Indonesia's knowledge, attitude, and practice (KAP) household survey. A composite measure was used to estimate the overall prevalence of handwashing with soap. The second study constructed a handwashing ladder and estimated its association with child diarrhea by using the recent Demographic and Health Survey in 25 countries in Sub-Saharan Africa (SSA). The third study developed a WASH Resource Index (WRI) by using the Uganda Demographic and Health Survey 2011 and examined the geographical distribution of high-risk WASH behaviors at the cluster level: drinking surface water without water treatment at point of use, open defecation, lack of a handwashing place for the household, and water collection time greater than 30 minutes. The association between the index and child diarrhea at the household level was also examined.

Results: The first study identified four potential determinants of handwashing with soap including: a desire to smell nice, interpersonal influences, the presence of handwashing places within 10 paces of the kitchen and the toilet, and key handwashing moments including after eating and after cleaning child stools. The second study revealed that

availability of water and soap at a handwashing place for the household 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. In other countries, availability of handwashing resources at a handwashing place was not significantly associated with child diarrhea. The third study suggested that high-risk WASH practices and child diarrhea were clustered in different geographical areas at the cluster level. At the household level, being in higher WASH quintiles was found to be associated with a lower prevalence of child diarrhea than that of the lowest WASH quintile.

Discussion: The use of non-health messages may effectively promote handwashing with soap in Indonesia. A composite measure of handwashing with soap, reflecting self-reporting, availability of handwashing materials, and handwashing demonstration, may produce a more accurate estimate of the overall levels of handwashing behaviors. Availability of water and soap at a handwashing place for the household remains an important facilitating factor for handwashing practices in SSA. A unique context of each country needs to be considered for promoting handwashing practices more effectively. High-risk WASH practices, particularly lack of a handwashing place and water collection time of greater than 30 minutes, were highly prevalent in Uganda. While promoting handwashing practices and access to drinking water, it is vital to address geographical disparities within each country to target the most vulnerable populations for greater investments.

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Chapter 1: Introduction

Historically, water, sanitation, and hygiene (WASH) have been recognized as the essential components of basic human needs, and global communities have striven to provide adequate WASH services worldwide. The United Nations declared the decade from 1981 to 1990 as the *International Drinking Water Supply and Sanitation Decade* and called for global efforts to achieve universal access to safe drinking water and basic sanitation (Graham, 2011). Although the goals were not achieved, it became the major milestone for the international community to aim for improving WASH conditions. In 2000, the Millennium Development Goals (MDGs) were set with a target to halve the proportion of global populations who do not have access to improved water sources and basic sanitation by 2015 (WHO/UNICEF, 2015). The post-2015 agenda, the Sustainable Development Goals (SDGs), also include a water and sanitation-related goal to keep the momentum to increase access to safe drinking water and sanitation (Hutton & Varughese, 2016).

Statement of Problem

Despite the notable global efforts, many people have not received adequate WASH services. Globally, 663 million people did not have access to improved water sources for their drinking water, and 2.4 billion people did not own improved sanitation facilities in 2015 (WHO/UNICEF, 2015). Of those people without access to improved water supply, 48% or 319 million people were living in Sub-Saharan Africa (SSA) (WHO/UNICEF, 2015). Moreover, 695 million people in SSA did not have access to

improved sanitation facilities (WHO/UNICEF, 2015). Thus, SSA has been disproportionately affected by inadequate WASH services. These indicators suggest that effective and continuous WASH interventions remain necessary to improve WASH in SSA and highlight the importance of examining the determinants of access to WASH services.

Limited access to WASH services has a major public health implication especially on young and school-aged children. More specifically, lack of access to safe drinking water, sanitation facilities, and handwashing behavior is the major risk factor of diarrhea, which accounted for 801,000 and 700,000 deaths among children under five years in 2010 and 2011 respectively (Liu, Johnson, Cousens et al., 2012; Walker, Rudan, Liu et al., 2013). The 2011 mortality data suggest that over 1,900 children lost their lives every day due to diarrhea (Walker et al., 2013). Moreover, Hutton and Haller (2004) estimated that 272 million days for school attendance have been lost every year owing to preventable diarrheal diseases; 400 million children in low-income countries also suffer from worm infections (e.g., hookworms), which impede students' optimal learning and proper physical growth due to compromised absorption of nutrients (Hall, Hewitt, Tuffrey et al., 2008). Thus, inadequate WASH has put a great deal of disease burden on children.

Gaps in Knowledge

Gaps in knowledge and practice still exist in the WASH sector. First, quantitative evidence remains limited regarding the determinants of handwashing with soap in some low- and middle-income countries. In Indonesia, for instance, formative studies have

been conducted to explore what promotes handwashing with soap (Greenland, Iradati, Ati et al., 2013; Rimbatmaja, Pooroe-Utomo, Semiarto et al., 2007), but few quantitative evidence has been collected. Understanding the promoters of handwashing with soap is therefore of vital importance for effective handwashing interventions.

Second, a handwashing ladder has not been developed to track the global progress in access to handwashing with soap. Despite the importance of personal hygiene or handwashing practice to prevent diarrheal outcomes, only water and sanitation ladders have been conceptualized and adapted to examine their association with child diarrhea (WHO/UNICEF, 2015; Fink, Günther, & Hill, 2011). The establishment of a handwashing ladder with empirical evidence can complement the existing ladders to monitor the global progress in access to WASH services and assess child health outcomes.

Lastly, high-risk WASH behaviors—drinking surface water without any effective treatment at point of use, open defecation, lack of handwashing, and taking at least 30 minutes for water collection—have not been examined together to estimate their geographic distributions and overall burden on populations. Examining the geographic distribution of an individual WASH problem remains essential to develop specific interventions for an affected area. This approach, however, does not address how other high-risk WASH practices are distributed and have created burdens in the same location. By assessing high-risk WASH practice together, the total burden associated with each geographic place and its reduction from improving a WASH practice can be estimated. The development of an index that represents the household WASH resources can also make methodological and practical contributions to the WASH sector.

Definition of Terms

WASH can be understood and interpreted in many ways. For the purpose of this dissertation, *water* means water for drinking and cooking for the household consumption, *sanitation* means human excreta disposal, and *hygiene* means behaviors for maintaining personal cleanliness. Accordingly, water, sanitation, and hygiene have independent roles and contributions in the WASH sector. Based on those specific definitions, water use for agricultural and industrial purposes was not considered in this study. Moreover, this research put emphasis on handwashing with soap as a key hygiene behavior to prevent diarrhea while other personal hygiene behaviors (e.g., washing face, bathing) remain important to prevent non-diarrheal health issues.

The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) created water and sanitation ladders to demonstrate the degree of improvements in access to WASH services (WHO/UNICEF, 2015). The water ladder consists of surface water, unimproved water sources, other improved water sources, and piped water. The sanitation ladder includes open defecation, unimproved sanitation facilities, shared facilities, and improved sanitation facilities (see Table 1). An improved water source for drinking water and an improved sanitation facility are defined as "one that, by the nature of its construction, adequately protects the source from outside contamination, particularly faecal matter" (p. 50) and "one that hygienically separates human excreta from human contact" (p. 50) respectively. The JMP also explained that improved drinking water sources consist of public taps, standpipes, boreholes, tube wells, protected wells, protected springs, and rain water while improved sanitation facilities include flush toilets connected to the sewer system, pit latrines, or septic tanks, pit

latrines with slabs, ventilated improved pit latrines, and composting toilets (WHO/UNICEF, 2015). Accordingly, WASH services can be provided at different levels of safety and protection against contamination.

Surface Water (Water Ladder 1) • Dam • Pond • River • Stream • Canal • Irrigation channels	**Open Defecation (Sanitation Ladder 1)** Definition: disposal of human feces in "fields, forests, bushes, open bodies of water, beaches or other open spaces or disposed of with solid waste" (WHO/UNICEF, 2014, p. 40).
Unimproved Sources (Water Ladder 2) • Unprotected spring • Unprotected dug well • Bottled water • Cart with small tank/drug	**Unimproved Facilities (Sanitation Ladder 2)** • Pit latrines (no slab or platform) • Hanging latrines • Bucket latrines
Other Improved Sources (Water Ladder 3) • Public taps/standpipes • Protected springs • Protected dug wells • Tube wells • Boreholes • Rainwater collection	**Shared Facilities (Sanitation Ladder 3)** • Improved sanitation facilities shared with two or more households
Piped Water on Premise (Water Ladder 4) • Piped water in the house, plot, or yard.	**Improved Facilities (Sanitation Ladder 4)** • Flush toilets • Ventilated improved pit latrine • Pit latrine with a slab • Composting toilet

Table 1. Water and Sanitation Ladder. Adapted from WHO/UNICEF, 2015.

Research Purpose & Study Approach

The overall purpose of this dissertation was to inform where and how future WASH interventions can be conducted by analyzing household survey data from Indonesia and Sub-Saharan African countries. This dissertation employed the three-paper model. Manuscript 1 assessed the potential determinants of handwashing with soap in Indonesia. Manuscript 2 conducted a quantitative analysis to examine the association

between the proposed handwashing ladder and child diarrhea outcome. Manuscript 3 constructed a WASH Resource Index and estimate its association with child diarrhea. A spatial analysis with primary sampling units was also conducted. As the study approach, the first paper conducted quantitative analysis with the household knowledge, attitude, and practice (KAP) survey data. The second and the third paper used the Demographic and Health Surveys and the Multiple Indicator Cluster Surveys for assessing quantitative evidence of handwashing and high-risk WASH practices.

Chapter 2:

Exploring determinants of handwashing with soap in Indonesia: A quantitative analysis

Introduction

Handwashing with soap at critical moments, such as before eating and after defecation, can prevent infectious diseases by interrupting the transmission of infectious agents. Empirical evidence suggests that handwashing with soap reduces the risk of diarrhea [1-3], acute lower respiratory infections [4], and soil-transmitted helminths [5], and it has been recognized as one of the most cost-effective health interventions to reduce the burden of disease [6]. Yet, only 19% of the global population is estimated to wash their hands with soap after using a sanitation facility or handling children's excreta [7].

Good hygiene is of vital importance in Indonesia due to the lack of basic sanitation in the country. Approximately 20% of the Indonesian population, or 51 million people, are estimated to defecate in open spaces, such as fields, bushes, and beaches [8]. Open defecation increases the risk of physical contact with fecal pathogens and can induce both short-term and long-term health consequences including diarrhea, stunting, and environmental enteropathy [9, 10]. In this context, handwashing with soap can serve as a primary barrier to disease transmission.

The Government of Indonesia (GoI) has promoted handwashing with soap as part of the national sanitation program, *Sanitasi Total Berbasis Masyarakat* (STBM) or the Community Approaches to Total Sanitation and Hygiene [11]. The STBM aims to

eliminate open defecation from 20,000 villages by 2019, and the five project pillars include eliminating open defecation, increasing the practice of handwashing with soap and household water treatment, and improving solid waste and wastewater management [11]. In November 2012, UNICEF and the GoI launched a four-year sanitation and hygiene project in eastern provinces of Indonesia to scale up and strengthen the efforts underway in the STBM program.

Determinants and Measurement of Handwashing Behaviors

Although handwashing may be understood as a simple task, multiple levels of influence or behavioral determinants exist to shape this behavior. Previous research has suggested that adult caregivers, female sex, higher levels of education, high socioeconomic status, place of residence, and access to water and sanitation are associated with handwashing with soap [4, 12, 13]. Habits of washing hands and motivations for cleanliness have also been identified as psychological determinants of handwashing with soap [14]. A review of formative studies from 11 countries in Asia, Africa, and South America further highlighted the roles of emotional drivers, such as disgust, comfort, and desire for social status, and suggested that health-related motivations may not always be the key determinant of handwashing behaviors [15]. Those socio-demographic, structural, and psychosocial factors identified in empirical research have informed the recent development of conceptual models and theoretical frameworks to design effective hygiene interventions [16, 17, 18].

Accurate measurement of behaviors is foundational for estimating the prevalence of handwashing with soap and assessing hygiene interventions. Yet, the difficulty of measuring handwashing behaviors is well-recognized [19]. Empirical evidence of handwashing practice has been collected by a number of measures including self-reports, rapid observations, microbiological assessment of hands, structured observations, and soap-sensor-based methods with varying levels of validity, feasibility, efficiency, and affordability [20]. While self-reported handwashing behaviors can be efficiently measured at relatively affordable cost, people tend to overestimate their handwashing practice [21, 22]. Observing a practical handwashing demonstrations is another relatively efficient approach to assess people's handwashing practice, but limited evidence exists to determine the effectiveness of this measurement [20]. Rapid observations of handwashing resources in the household, such as presence of soap, water and a dedicated handwashing location, may provide a reliable estimate of handwashing behaviors, but they cannot assess the frequency and consistency of handwashing behaviors at critical moments for each person [20].

Structured observations, where researchers directly observe people's handwashing behaviors for a few hours or more, can collect rich contextual data and objective measures of handwashing practice at critical moments including after defecation [23]. By assuming that structured observations can yield the best available estimate of actual handwashing behaviors, this method has been used as a standard of comparison to assess the performance of other proxy measures, such as self-reports and rapid observations [21, 22, 24]. This measurement, however, is often time-consuming and labor-intensive, which

may not be feasible or appropriate for a large household survey. Thus, a single universal method of handwashing measurement that suits every research setting does not exist [20].

While formative research has explored how people may be motivated to wash their hands with soap in Indonesia [25, 26], quantitative evidence remains limited to inform the behavioral determinants of handwashing with soap in Indonesia and associated interventions. The limitations of self-reports, handwashing demonstration, and rapid observations of handwashing resources have been identified [20], but few studies have examined the effectiveness of a composite measure to assess handwashing with soap through a household survey.

In this study, we aimed to identify the potential determinants of handwashing with soap, estimated by the use of a composite measure for each household enrolled that includes: 1) self-reported handwashing with soap, 2) an observed handwashing demonstration, and 3) observation of handwashing materials (i.e. soap and water) available to household members. Applying this composite measure, the study aimed to assess how motivational drivers, key times that individuals wash their hands, and the presence of a handwashing place in the household are independently as well as collectively associated with handwashing with soap. Respondent's age, sex, education, place of residence, household wealth levels, access to water for household needs, and ownership of a private toilet were included in the analysis. Motivations were included as the psychological determinants of handwashing behaviors. Handwashing moments (e.g., after defecation) and presence of handwashing place in the household were regarded as physical cues to induce

handwashing with soap. It was hypothesized that motivations for handwashing, self-reported handwashing moments, and access to handwashing facilities would be significantly associated with handwashing with soap, which might be collectively moderated by socio-demographic characteristics and structural factors.

Methods

Data & Sampling

In February 2014, UNICEF conducted a knowledge, attitude, and practice (KAP) survey to establish a baseline of sanitation and hygiene conditions in selected communities at the beginning of STBM implementation. UNICEF specifically selected six districts, which are typically more resource-constrained and have low levels of access to sanitation in Indonesia. Based on the multi-stage cluster sampling method, 2,036 households were initially identified and contacted by house-to-house visits. A total of 1,786 households had someone at home, and 1,700 agreed to participate in the survey, attaining the participation rate of 95.2%. The questionnaire was orally administered in the local language after obtaining informed consent. Study participants were from six districts of Indonesia across three provinces, including Alor, Sumba Timur (NTT Province), Luwu Utara, Takalar, Barru (South Sulawesi Province), and Jayapura (Papua Province) (Table 1).

Study variables

The outcome variable of this study was handwashing with soap, measured using three indicators of handwashing. First, respondents were asked what they usually use to wash

their hands without any prompt. Second, the availability of water and soap at a handwashing place in the household was assessed through direct observation. Lastly, the research team asked respondents to show how they usually wash their hands and directly observed the materials used for their handwashing demonstration. Study participants were regarded as performing handwashing with soap in this study if they reported to wash hands with water and soap, water and soap were observed at the handwashing place, and use of water and soap was observed during the handwashing demonstration. This study used the composite measure of handwashing with soap for all the bivariate and multivariate analyses unless stated otherwise.

The exposure variables of interest included psychosocial and structural factors that may influence handwashing behaviors. A psychosocial factor examined in this study was people's motivations for handwashing. Respondents were asked what motivates them to wash their hands in an open-ended question without any prompt or any limit to the number of responses that they can give. Each response was recorded as one of the nine reasons derived from literature search on sanitation and hygiene in Indonesia (1 = to prevent the spread of disease, 2 = to be clean, 3 = to smell good, 4 = to get rid of dirt/smell/sticky things on my hands, 5 = religious reasons/beliefs, 6 = was told it was the right thing to do, 7 = because that's what everyone does, 8 = don't know, 9 = other), and indicator variables (0 = not mentioned, 1 = mentioned) were constructed for each motivational factor.

This study also assessed seven handwashing opportunities or moments, which consisted of before cooking, before eating, after eating, before feeding a child, after cleaning child stools, after defecation, and after work. As with motivations for handwashing, respondents were asked when they usually wash their hands without prompt, and indicator variables were made for each handwashing opportunity (0 = not mentioned, 1 = mentioned). For a structural factor, access to handwashing facilities in the household was directly observed and recorded with the following categories: within 10 paces of the toilet facility, within 10 paces of the kitchen, elsewhere in the household, outside of the yard, and no specific place.

Control variables for this study consisted of respondents' age, sex, education, district, household size, access to water and sanitation, and wealth quintile. Household size represented the number of family members who live together. Access to water indicated whether the household reported to have access to water for household needs throughout the year (0 = No, 1 = Yes). Access to sanitation represented if the household reported to own a private sanitation (0 = No, 1 = Yes). As a proxy measure of socioeconomic status, the wealth quintile was developed with 12 variables that represent household assets and characteristics (i.e., radio, TV, mobile phone, telephone, refrigerator, motorcycle, bicycle, animal drawn cart, car/truck, boat with motor, own agriculture land, own farm animals) by conducting the principal component analysis [27].

Statistical Analysis

This study employed STATA 13 to perform univariate, bivariate, and multivariate

analyses [28]. Bivariate and multivariate analyses were adjusted for the complex survey design by using available sampling units. Descriptive statistics of all study variables were calculated to provide the general characteristics of the study population (Table 1). The proportion of respondents who wash hands with soap by study characteristics was also estimated while performing the test of independence. Bivariate associations between key exposure variables and the outcome variable were assessed with generalized linear models (GLM) with Poisson Family and log link to produce the prevalence ratio of handwashing with soap. Lastly, multivariate nested GLM models were run to estimate the extent to which socio-demographic characteristics, access to water and sanitation, and wealth quintiles moderate the main effect of each independent variable on handwashing with soap. Model 1 incorporated all of the control variables including respondents' age, household size, education, biological sex, district, household wealth, and self-reported access to water and a private toilet as the baseline specification. Model 2 added people's motivations for handwashing to the baseline model. Model 3 added directly observed handwashing locations in the household to the baseline specification. Model 4 included self-reported moments when respondents usually wash hands. Model 5 included all of the independent and control variables.

Due to the issue of multicollinearity (e.g., Variance Inflation Factor >=5), Alor and Sumba Timur were both included as the reference group of the district variable in the multivariate analysis. This study also examined if the presence of a handwashing place near the kitchen and the toilet is associated with handwashing with soap before cooking and after defecation, respectively. Neither of the hypothesized interaction effects was

statistically significant, and thus, multivariate models only assessed the main effects of independent variables.

Results

The descriptive characteristics of study participants are summarized in Table 1. The majority of respondents were aged 35 to 55 and came from a household with four to six people. Over 75% of respondents completed at least primary education. Male and female respondents were almost equally represented in this study. The sample distribution by districts ranged from 9.1% in Jayapura to 23.9% in Luwu Utara in accordance with the population size of each district. Each wealth quintile represented approximately 20% of respondents. Most of the households (87.9%) had access to water throughout the year, and 61.5% had a private sanitation facility in the household overall.

The top three self-reported reasons or motivations for handwashing were to be clean (89.6%), to prevent the spread of disease (52.9%), and to get rid of dirt/smell/sticky things (37.5%). Approximately 60% of households had access to a handwashing place within 10 paces of the toilet or the kitchen, and 19% had a handwashing station in other locations around the household. However, 21.3% did not have a specific location for handwashing. Lastly, almost 90% of respondents reported to wash hands before eating, with only 56.6% of people reporting to wash hands after eating and 52.1% after defecation. Only 7.6% and 13.4% of respondents reported to wash hands before feeding a child and after cleaning child stools, respectively. These results suggested that many

respondents do not wash hands at all of the critical moments including before cooking, before eating, before feeding a child, after cleaning child stools, and after defecation.

(Table 1)

Major differences were observed for the prevalence of handwashing with soap between the individual measures of handwashing and the composite measure (Table 2). While self-reports, direct observations of handwashing materials, and direct observations of handwashing demonstration suggested that over 70% of respondents wash hands with soap, the composite measures provide much lower estimates ranging from 55.7% to 63.9%. The highest estimate of handwashing with soap was 75.2% by direct observations of handwashing demonstration. Some respondents may have demonstrated a better handwashing behavior than their typical behavior, partially due to the presence of the observer. The lowest estimate for handwashing with soap was 55.7% by the composite measure of observed handwashing materials and handwashing demonstration. Adding a criterion of self-reported use of water and soap to this composite measure did not change the estimate of handwashing with soap.

Bivariate analysis

The prevalence of handwashing with soap at critical moments was very low. Based on the composite measure, only 26.7% and 52.0% of respondents were estimated to wash hands with soap after defecation and before eating, respectively. The prevalence was even lower before feeding children (4.0%) and after cleaning child stools (6.9%), and only 1.8% of respondents were estimated to wash hands with soap at these four critical moments.

(Table 2)

The proportion of older adults who washed hands with soap (49.4%) was lower than that of young adults (56.3%) and middle-aged adults (57.0%) (see Supplemental Materials, Table 1). The estimated prevalence of handwashing with soap by household size ranged from 51.9% in small households to 59.6% in large households. Female and male respondents had the same prevalence of handwashing with soap, at 56%. Statistical tests of independence suggested that age, household size, and sex were not significantly associated with the handwashing outcome in this study (Supplemental Materials, Table 1).

The respondent's education, the district the household was located in, household wealth, and access to water and sanitation were significantly associated with the behavior of handwashing with soap, and the calculated prevalence is presented in Figure 1. While over 58% of respondents with primary, pre-secondary, or secondary or higher education wash their hands with soap, only 43.5% of respondents with less than primary education washed their hands with soap. A large gap in the prevalence of handwashing with soap also existed between the six districts, ranging from 32.4% in Alor to 83.6% in Takalar. A positive curvilinear trend in the percentage of handwashing with soap was found for the quintiles of wealth. In the lowest wealth quintile, only 27.5% of respondents wash hands with soap, while 72.0% in the highest quintile performed handwashing with soap. Lastly, the majority of respondents, 58.2% and 59.5% respectively, reported to have access to water and a private toilet washed their hands with soap.

(Figure 1)

Table 3 presents the proportion of respondents who wash hands with soap by self-reported motivations for handwashing, observed locations of the place for handwashing, and self-reported handwashing moments. The estimated prevalence of handwashing with soap by motivations ranged from 30.7% to 75.0%. Four motivations for handwashing – disease prevention, good smell, aesthetic purposes, and the belief that others in the community wash their hands with soap (i.e. descriptive norms) – were significantly associated with handwashing with soap, though not always a positive association. Having a motivation for good smell was associated with a 34.2% higher prevalence of handwashing with soap than that of respondents without this motivation. In contrast, motivations for disease prevention, removal of dirt, and the belief that others in the community wash their hands were associated with a lower prevalence of handwashing with soap than those who did not report these motivations.

The majority of respondents who had access to a handwashing place within 10 paces of the kitchen and the toilet facility was estimated to wash their hands with soap. Compared to respondents without a specific location for handwashing in the household, the prevalence of handwashing with soap was on average 24% and 37% higher among those respondents who had a handwashing place within 10 paces of the kitchen and the toilet, respectively.

The estimated prevalence of handwashing with soap by self-reported handwashing moments ranged from 39.3% before cooking to 63.0% after eating. Five handwashing moments, including before cooking, before eating, after eating, after defecation, and after

work were significantly associated with handwashing with soap. The direction of associations, however, was not uniform. Reporting to wash hands before eating and after eating were associated with a higher prevalence of handwashing with soap than those who did not report to wash hands at these respective moments. The other handwashing moments (i.e., before cooking, after defecation, after work), however, were negatively associated.

(Table 3)

Multivariate analyses

The results of nested GLM regression analysis are presented in Table 4. In Model 1, household size, a private sanitation facility in the household, district, and wealth levels were significantly associated with handwashing with soap, controlling for other variables. The prevalence of handwashing with soap in the highest wealth quintile was 89% higher than that of the lowest quintile of wealth. These findings are in accordance with previous research that highlighted the roles of socio-economic and structural factors as potential determinants of handwashing with soap.

In Model 2, motivations of good smell and interpersonal influence were positively associated with handwashing with soap while negative associations were found for the aesthetic reason (i.e., to get rid of dirt, smell, sticky things on hands) and the descriptive norm (i.e., perceiving that other people wash hands with soap). By holding other variables constant, respondents who washed their hands for good smell and interpersonal influence (i.e., being told that it was a right thing to do) were associated with having 26.2% and 26.0% higher prevalence of handwashing with soap than other respondents

without these motivations. Having a motivation to remove dirt, smell, or sticky materials on their hands was associated with 20.6% lower prevalence of handwashing with soap than those respondents without this motivation.

In Model 3, respondents who have a handwashing place within 10 paces of the kitchen and the toilet were associated with 28.2% and 46.7% higher prevalence of handwashing with soap, respectively, than those respondents who do not have a specific handwashing place. Thus, the presence of handwashing stations in the household may be a key structural determinant or enabling environment of handwashing with soap. By adding the handwashing place to the baseline specification, the association between self-reported ownership of a private toilet and handwashing with soap was no longer statistically significant. This result suggests that the presence of handwashing stations may mediate the independent effect of the sanitation variable on handwashing with soap, highlighting the need for promoting handwashing stations around the household sanitation facility or the kitchen to facilitate handwashing with soap.

In Model 4, four handwashing moments, including before cooking, before eating, after eating, and before feeding children, were significantly associated with handwashing with soap when holding other variables constant. The prevalence of handwashing with soap among respondents who reported to wash hands before cooking was 26.0% lower than that of respondents who did not report to wash hands at this handwashing moment. This finding suggests that people do not often use soap for their handwashing before cooking, and consequently food preparation may remain an important pathway for food

contamination. Respondents who reported to wash their hands at the other three handwashing moments had a higher prevalence of handwashing than the respondents who did not report to wash hands at these moments. In this model, household size lost its significant association with handwashing with soap. This may be a reason that the independent effect of household size is significant in the previous regression models, which do not assess the association of handwashing moments with handwashing behaviors. The analysis suggests that in Model 4, self-reported handwashing moments may mediate the association between household size and handwashing with soap.

Most of the variables maintain their significant association with handwashing with soap in Model 5, except for a few self-reported motivations and handwashing moments. In this model, cleanliness, good smell, aesthetic motivations, religious reasons, and interpersonal influence have significant associations with handwashing with soap while the descriptive norm is no longer significant. Self-reported handwashing moments that include before cooking, after eating, and after cleaning child stools were significantly associated with the outcome.

(Table 3)

Discussion

This study explored potential determinants of handwashing with soap in six districts across three provinces of Indonesia. The results suggested that structural factors, namely household wealth levels, district of residence, and presence of handwashing infrastructure within 10 paces of the kitchen and the toilet, are associated with greater handwashing with soap in the context of this study. Motivations for handwashing, such as good smell

and interpersonal influence, were also identified as factors associated with handwashing with soap. The analysis further highlighted that handwashing with soap is more common at certain handwashing moments, mainly after eating and after cleaning child stools, than other critical times, such as after defecation or before food preparation.

The estimated prevalence of handwashing with soap by the composite measure was lower than that of individual measures of handwashing in this study. Although this study cannot assess the validity of the composite measure by comparing the estimated prevalence with that of structured observations, a more conservative estimate of handwashing behavior was obtained. The findings in this study can be interpreted to indicate that the combination of multiple indicators, rather than one indicator, may be more useful for household surveys and reduce the risk of overestimating handwashing behaviors. The Demographic and Health Surveys (DHS) and the Multiple Indicator Cluster Survey (MICS) only collect data on the presence of soap and water for handwashing in the household as the proxy measure of handwashing behaviors. Handwashing measurement in these large household surveys could potentially be strengthened by including the direct observation of handwashing demonstration and developing a composite measure to estimate the prevalence of handwashing with soap in low- and middle-income countries.

Descriptive analysis revealed that Alor has the lowest prevalence of handwashing with soap, which could have been induced by limited access to water in this district. A further analysis of the data found that only 46.2% of households in Alor were estimated to have access to water throughout the year, compared to at least 87% or higher in other districts.

In focus group discussions conducted by UNICEF, a female participant from Alor also stated that "I will not let my kids wash their hands unless we have enough water, since getting water is difficult and our priority is for drinking and cooking" (p.28) [11]. Adequate access to drinking water is therefore an important precursor to perform handwashing with soap. Nonetheless, a multivariate analysis did not find a significant association between having year-round access to water and handwashing with soap. Future research may modify this indicator and collect information on the quantity of water that households can access.

The drivers that form hygiene habits or change individual and community-level hygiene behaviors are not fully understood. In this study, disease prevention did not appear to be a primary driver for handwashing with soap. By recognizing that handwashing may not be always facilitated by health-related motivations, previous research has explored the potential roles of emotional drivers (e.g., disgust, comfort) and sociocultural factors (e.g., norms, habit formation) for handwashing promotion [16, 19]. Disgust has also been used to promote handwashing with soap in different cultural contexts [29, 30], and a recent cluster-randomized trial revealed that handwashing behaviors can be affected by addressing disgust as a key emotional driver [31]. In this study, a motivation for handwashing—*removal of dirt, smell, or sticky things on hands*—was used as a proxy measure for disgust. This motivation, however, was found to be associated with reduced levels of handwashing with soap. This finding could suggest that this was a poor proxy of disgust or that disgust was not a compelling driver of increased handwashing. Additional

evidence is needed to understand how emotional drivers may more effectively impact handwashing with soap.

Interpersonal influence was also identified as an influential factor for handwashing promotion. A qualitative study with the same study population revealed that local authorities, community health workers, and religious leaders are influential sources of information on sanitation and hygiene in this study context [11]. Accordingly, promoting handwashing with soap through these information providers may effectively enhance people's handwashing behaviors. Moreover, evidence suggests that habits can play a major role in shaping people's handwashing behaviors [16, 32]. Government-led handwashing promotion efforts for adult populations may be complemented with school-based handwashing interventions to form the habit of handwashing with soap among children though the experience of UNICEF Indonesia has been that handwashing rates in schools still remains low, and this message needs constant reinforcement for sustainability.

Handwashing moments appeared to provide varying levels of physical cues to induce handwashing with soap. The results suggested that handwashing with soap was more commonly practiced after eating and less commonly practiced before cooking. While the exact reasons for limited handwashing with soap before cooking remain unclear in this study, people may be washing hands with soap inconsistently or wash hands with water only. This finding is in accordance with earlier formative research in Serang district of Indonesia, which reported that new mothers infrequently and inconsistently practiced

handwashing at critical moments including before cooking [25]. While hygiene interventions for both men and women remain vital for improving public health, tailoring educational messages to a specific population group or sex may improve handwashing practices before cooking. Also, previous research identified after eating as a common handwashing moment despite the low priority of this practice from a public health perspective [16]. The cultural practice of using hands to eat food may be a driver for people to wash hands with soap after completing their meal. Lastly, the low level of handwashing with soap after defecation identified in this study remains a major public health concern in Indonesia where open defecation is commonly practiced [8]. To protect the population from infectious diseases, the importance of handwashing with soap and ownership of household sanitation facilities needs to be further emphasized and promoted in this context.

There are some important limitations to this study. First, self-reported data could be influenced by social desirability bias [20]. The study team informed potential study participants that the purpose of this study was to ask them about water, sanitation, and hygiene (WASH) and health conditions in the household. This process could have prompted respondents to mention disease prevention as a motivator for handwashing practice and report handwashing moments that people should wash hands rather than their true hygiene behaviors. To minimize this bias, however, this study explored respondents' handwashing motivations and handwashing moments through an open-ended question without the use of any prompts. Second, this study employed cross-sectional data for statistical analyses, so the temporality of independent and dependent

variables cannot be ascertained. Reverse causation could be a possibility. Third, handwashing with soap estimated by the composite measure does not necessarily reflect people's true behavior. A great deal of empirical evidence has confirmed that self-reported handwashing behaviors tend to be overestimated and are not reliable, and structured observations may be subject to reactivity [20]. As previously stated, other measurement methods also have both advantages and disadvantages of measuring handwashing behaviors. As such, this study combined three measurement methods to estimate the prevalence of handwashing with soap. While the estimated prevalence of handwashing with soap was 71.2% by only using the self-reported measure, it was estimated as 55.7% based on the composite measure. Thus, this study addressed the measurement errors to the extent that is possible with available data. Lastly, data on the primary sampling unit were not available in this study, so the tertiary sampling unit was used to adjust for the clustering effect as the best available option. Although the point estimate would not be altered, confidence intervals and statistical significance are likely to be different if the primary sampling unit data were available.

To generate a research agenda for the future, we conducted a post-hoc correlation analysis to assess the association between self-reported motivations for handwashing and three handwashing moments—after defecation, before eating, and after cleaning child stools. This analysis revealed that motivations for disease prevention, cleanliness, good smell, interpersonal influence and descriptive norms were positively associated with self-reported handwashing after defecation. Cleanliness and good smell were positively associated with handwashing before eating while a negative association was found for the

aesthetic motivation. Lastly, disease prevention and aesthetic motivations were positively associated with handwashing after cleaning child stools. Accordingly, motivational drivers differently function to influence people's handwashing practices at each critical handwashing moment. To promote handwashing with soap at critical moments more effectively, future research can further examine what motivations are associated with people's handwashing practices at each handwashing moment.

Conclusion

This study identified some of the potential determinants of handwashing with soap by highlighting the substantial effects of structural and psychosocial factors. Physical proximity to handwashing stations has been shown to facilitate handwashing behaviors. Future interventions that send the message of good smell and comfort associated with handwashing may be also effective to promote the practice of handwashing with soap. More efforts are necessary to understand which key drivers for handwashing could effectively increase the practice of handwashing with soap at each critical moment, along with increased operational guidance on how to change his personal hygiene behavior at scale and maintain the behavior as a habit.

Handwashing with soap is a cost-effective strategy to reduce global burden of disease. Yet, this hygiene behavior has not been fully recognized as a global health priority. While water and sanitation have been included in the Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs), the progress on hygiene promotion has not been tracked globally. While the evidence base of handwashing measurement is not

complete, this study revealed a potential utility of composite measures to monitor and evaluate the progress of handwashing promotion. Developing credible indicators to monitor handwashing behaviors can be the first step to further highlight the importance of hygiene behaviors in global health.

Disclaimer: The opinions expressed are those of the authors and do not necessarily reflect the views of their institutions, UNICEF or the United Nations. The authors do not have any competing interests.

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Table 1. Descriptive analysis of study variables. n=1,696

Characteristics	*n*(%)
Age	
Young (aged 18–35)	610 (36.0)
Middle (aged 36–55)	848 (50.0)
Older (aged 56 or older)	238 (14.1)
Household size	
Small (1–3)	461 (27.2)
Middle (4–6)	963 (56.8)
Large (7 or more)	271 (16.0)
Education	
Less than primary education	418 (24.6)
Primary education	426 (25.1)
Pre-secondary education	346 (20.4)
Secondary or higher	506 (29.8)
Sex	
Female	853 (50.3)
Male	843 (49.7)
District	
Alor	245 (14.4)
Sumba Timur	278 (16.4)
Luwu Utara	404 (23.9)
Takalar	364 (21.5)
Barru	251 (14.8)
Jayapura	154 (9.1)
Wealth quintile	
Poorest	333 (19.6)
Poorer	327 (19.3)
Middle	336 (19.8)
Richer	364 (21.4)
Richest	337 (19.9)
Reported to have water for household needs throughout the year	1492 (87.9)
Reported to have a private toilet	1043 (61.5)
Self-reported reasons for handwashing	
To prevent the spread of disease	896 (52.9)
To be clean	1519 (89.6)
To smell good	311 (18.3)
To get rid of dirt/smell/sticky things	636 (37.5)
Religious reasons	11 (0.7)
Being told that it was the right thing to do	65 (3.8)
Because that is what everyone does	26 (1.5)
Observed place for habitual handwashing	
No specific place	361 (21.3)
Outside of yard	95 (5.6)
Elsewhere in home or yard	228 (13.4)
Within 10 paces of the kitchen/cooking space	746 (44.0)
Within 10 paces of the toilet facility	266 (15.7)
Self-reported moments when respondents usually wash hands	
Before cooking	270 (15.9)
Before eating	1520 (89.7)
After eating	926 (54.6)
Before feeding a child	129 (7.6)
After cleaning feces of a child	227 (13.4)
After defecation	884 (52.1)
After work	749 (44.2)

Table 2. Handwashing with soap estimated by self-reports, direct observations, and a composite measure. n=1,696

Measurement Methods	*n* (%)
Self-reported use of water and soap for handwashing (HW1)	1,208 (71.2)
Observed presence of water and soap at the handwashing place (HW2)	1,190 (70.2)
Observed use of water and soap during handwashing demonstration (HW3)	1,275 (75.2)
HW1 & HW2	995 (58.7)
HW1 & HW3	1,084 (63.9)
HW2 & HW3	944 (55.7)
HW1 & HW2 & HW3 (Outcome variable of this study)	944 (55.7)
HW1 & HW2 & HW3 & reported to wash hands after defecation	453 (26.7)
HW1 & HW2 & HW3 & reported to wash hands before eating	882 (52.0)
HW1 & HW2 & HW3 & reported to wash hands before feeding children	67 (4.0)
HW1 & HW2 & HW3 & reported to wash hands after cleaning child stools	117 (6.9)
HW1 & HW2 & HW3 & reported to wash hands at these four moments	31 (1.8)

Table 3. Unadjusted GLM regression (Family: Poisson, Link: log) of handwashing with soap by selected variables. n = 1,696

	Number and percentage of respondents with this response who wash hands with soap n(%)	Number and percentage of respondents without this response who wash hands with soap n(%)	PR (95% CI)	p-value
Self-reported motivations for handwashing				
To prevent the spread of disease	447 (49.8)	498 (62.2)	0.80 (0.72, 0.89)	**<0.001**
To be clean	833 (54.8)	112 (63.2)	0.87 (0.75, 1.01)	0.060
To smell good	233 (75.0)	711 (51.3)	1.46 (1.31, 1.63)	**<0.001**
To get rid of dirt/smell/sticky things	288 (45.4)	656 (61.9)	0.73 (0.65, 0.83)	**<0.001**
Religious reasons	7 (59.6)	938 (55.7)	1.07 (0.65, 1.76)	0.786
Being told that it was a right thing to do	38 (58.7)	906 (55.6)	1.06 (0.85, 1.31)	0.612
Because that is what everyone does	8 (30.7)	936 (56.1)	0.55 (0.31, 0.98)	**0.043**
Directly observed handwashing place				
Outside of the yard	33 (34.3)	174 (48.2)	0.71 (0.49, 1.04)	0.077
Elsewhere in the household	116 (50.8)	174 (48.2)	1.05 (0.85, 1.30)	0.627
Within 10 paces of the kitchen/cooking space	445 (59.7)	174 (48.2)	1.24 (1.03, 1.49)	**0.024**
Within 10 paces of the toilet facility	177 (66.3)	174 (48.2)	1.37 (1.12, 1.69)	**0.003**
Self-reported moments of habitual handwashing				
Before cooking	106 (39.3)	838 (58.8)	0.67 (0.56, 0.80)	**<0.001**
Before eating	882 (58.0)	62 (35.5)	1.63 (1.27, 2.09)	**<0.001**
After eating	584 (63.0)	360 (46.8)	1.35 (1.18, 1.53)	**<0.001**
Before feeding a child	67 (52.2)	877 (56.0)	0.93 (0.76, 1.14)	0.496
After cleaning feces of a child	117 (51.6)	827 (56.3)	0.92 (0.79, 1.06)	0.243
After defecation	453 (51.3)	491 (60.5)	0.85 (0.76, 0.94)	**0.002**
After work	349 (46.5)	596 (62.9)	0.74 (0.65, 0.84)	**<0.001**

* $p<0.05$, ** $p<0.01$, *** $p<0.001$. PR = prevalence ratio

Notes: Respondents were free to mention multiple motivations for handwashing and moments when they usually wash hands. Each self-reported motivation is a binary variable in which respondents who did not mention a given motivation represent a reference group.

Table 4. Multivariate GLM regression (family: Poisson, link: log) of handwashing with soap presented in prevalence ratio. Indonesia, 2014. n = 1,696

	model 1	model 2	model 3	model 4	model 5
Respondents' age (Ref: 18–35 years)					
36–55	1.022	1.031	1.031	1.052	1.069
56 or older	0.926	0.910	0.937	0.946	0.942
Household size (Ref: 1–3 people)					
4–6	1.031	1.052	1.036	1.008	1.033
7 or more	1.180*	1.190*	1.146*	1.112	1.102
Education (Ref: Less than primary)					
Primary	0.943	0.924	0.966	0.932	0.947
Pre-secondary	0.936	0.912	0.974	0.932	0.953
Secondary or higher	0.961	0.948	0.983	0.943	0.956
Female (Ref: Male)	1.002	0.997	0.981	0.985	0.969
District (Ref: Alor and Sumba Timur)					
Luwu Utara	1.141	1.211	1.149	1.032	1.091
Takalar	1.788***	1.785***	1.663***	1.755***	1.626***
Barru	1.482**	1.532***	1.443**	1.479**	1.481**
Jayapura	0.764	0.732	0.654*	0.719	0.605**
Wealth Quintile (Ref: Poorest)					
Poorer	1.535**	1.465**	1.587***	1.420**	1.438**
Middle	1.666***	1.586**	1.683***	1.567**	1.538**
Richer	1.737***	1.706***	1.757***	1.626***	1.654***
Richest	1.876***	1.780***	1.833***	1.774***	1.691***
Have access to water (Ref: No)	1.069	1.060	1.133	1.028	1.089
Have a private sanitation facility (Ref: No)	1.135*	1.120*	1.093	1.115	1.081
Self-reported motivations for handwashing:					
To prevent the spread of disease		1.087			1.078
To be clean		0.890			0.871*
To smell good		1.262***			1.234***
To get rid of dirt/smell/sticky things on hands		0.794***			0.819***
Religious reasons		1.420			1.574*
Being told that it was the right thing to do		1.260*			1.230*
Because that is what everyone does		0.571*			0.605
Observed HW place (Ref: No specific place)					
Outside of yard			0.878		0.836
Elsewhere in the household			1.086		1.096
Within 10 paces of the kitchen/cooking space			1.282**		1.267**
Within 10 paces of the toilet facility			1.466***		1.362***
Self-reported handwashing moments:					
Before cooking				0.740***	0.763***
Before eating				1.271*	1.223
After eating				1.177**	1.163**
Before feeding				1.271*	1.182
After cleaning child stools				1.119	1.192*
After defecation				1.022	1.007
After work				0.918	0.944
Adjusted Wald test: F-statistic	7.02	7.59	7.35	7.55	6.67
Df	(18, 327)	(25, 320)	(22, 323)	(25, 320)	(36, 309)

Notes: * p<0.05, ** p<0.01, ***p<0.001. Respondents were free to mention multiple motivations and handwashing moments in an open ended question without any prompt.

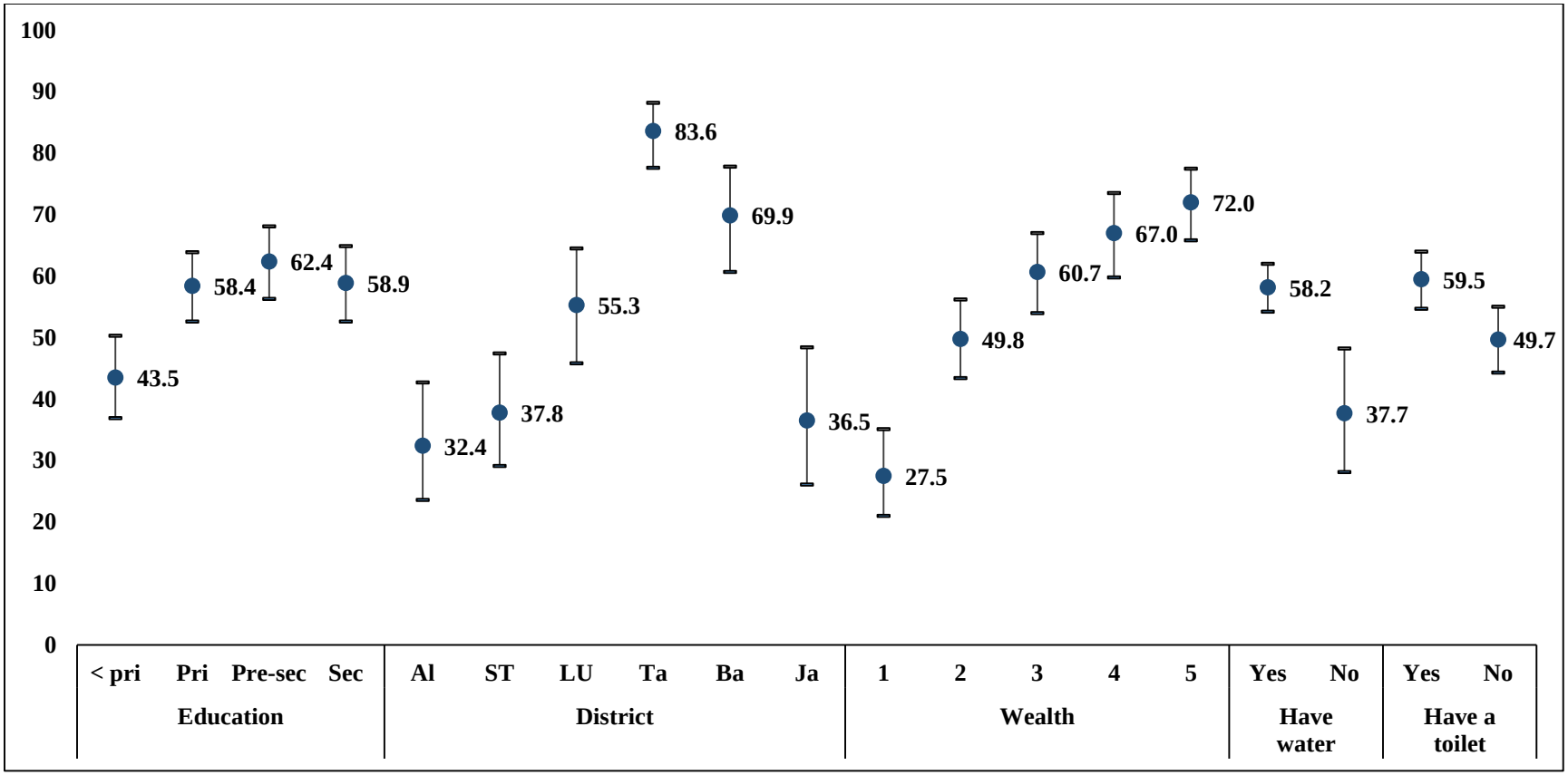

Figure 1. Percentage of respondents who washed hands with soap by education, district, wealth, and access to water and sanitation.
Notes: Al = Alor, ST = Sumba Timur, LU = Luwu Utara, Ta = Takalar, Ba = Barru, Ja = Jayapura

Supplemental Materials (Table 2.5)

Supplemental Materials, Table 1. Proportion of respondents who wash hands with soap by study variables. n = 1696.

	% HWWS (95% CI)	p-value
Age		0.13
Young (18–35 years)	56.3 (51.0, 61.5)	
Middle (36–55 years)	57.0 (52.6, 61.3)	
Older (56 years or older)	49.4 (42.4, 56.4)	
Household size		0.16
Small (1–3 people)	51.9 (45.6, 58.0)	
Middle (4–6)	56.4 (52.1, 60.6)	
Large (7 or more)	59.6 (52.8, 66.1)	
Education		**0.0001**
Less than primary	43.5 (36.9, 50.3)	
Primary	58.4 (52.6, 63.9)	
Pre-secondary	62.4 (56.3, 68.1)	
Secondary or higher	58.9 (52.6, 64.9)	
Sex		0.96
Female	55.7 (51.6, 59.8)	
Male	55.6 (51.0, 60.2)	
District		**<0.0001**
Alor	32.4 (23.6, 42.7)	
Sumba Timur	37.8 (29.1, 47.4)	
Luwu Utara	55.3 (45.8, 64.5)	
Takalar	83.6 (77.6, 88.2)	
Barru	69.9 (60.7, 77.8)	
Jayapura	36.5 (26.1, 48.4)	
Wealth Quintile		**<0.0001**
Poorest	27.5 (21.0, 35.1)	
Poorer	49.8 (43.4, 56.2)	
Middle	60.7 (54.0, 67.0)	
Richer	67.0 (59.8, 73.5)	
Richest	72.0 (65.8, 77.5)	
Have water for household needs throughout the year		**0.0003**
Yes	58.2 (54.2, 62.0)	
No	37.7 (28.1, 48.2)	
Have a private toilet		**0.0049**
Yes	59.5 (54.7, 64.0)	
No	49.7 (44.3, 55.0)	

Notes: A chi-square test was used for this analysis.

Chapter 3:

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

Introduction

Diarrheal diseases remain one of the leading causes of under-5 mortality worldwide [1]. In 2011, 700,000 children lost their lives for diarrhea, and Sub-Saharan Africa accounted for 50% of the mortality [2]. Although diarrhea incidence slightly declined from 3.4 to 2.9 episodes per child year between 1990 and 2010, multiple cases of diarrhea have placed a great deal of disease burden on children [3]. Inadequate access to safe drinking water, basic sanitation, and hygiene practice still account for 58% of diarrheal deaths globally [4]. Diarrhea prevention through water, sanitation, and hygiene (WASH) interventions is therefore vital to protect and facilitate the optimal growth and well-being of each child.

Handwashing with soap has been estimated to reduce the risk of diarrhea by 23% to 48% [5, 6, 7], and hygiene promotion is recognized as a cost-effective public health intervention to avert disease burden [8]. However, the proportion of the global population who practice handwashing with soap is very low. The estimated prevalence of handwashing with soap after using the toilet or contacting excreta is 19% globally, and it is lowest in Sub-Saharan Africa at 14% [7]. Empirical evidence from 11 countries also suggested that rates of handwashing with soap at other critical moments including before feeding and before cooking are also low, and handwashing is often performed with water

only [9]. To promote handwashing with soap more effectively, previous research examined what drives people's handwashing behaviors and developed a few conceptual models to explain how handwashing habits can be formed [10, 11, 12].

Handwashing with soap may be shaped or facilitated by addressing its determinants, but accurate measurement of this behavior remains difficult. While handwashing can be efficiently measured by self-reports, people tend to overestimate their behaviors [13, 14]. Alternative measures of handwashing behaviors include *proxy measures*, such as observing the availability of handwashing materials in the household and testing microbiological contamination of hands, and *direct measures*, such as structured observations and video observations [15]. Of these measurement approaches, rapid observations of handwashing 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 [15].

Although the presence of handwashing materials in the household does not provide information on frequency and timings of handwashing behaviors, this proxy measure can be useful to monitor the progress in improving access to handwashing 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 [16]. A handwashing ladder has also been proposed with three ladders: 1) no handwashing facility present; 2)

handwashing facility present without water or soap; and 3) handwashing facility present with water and soap [17]. DHS and MICS now include these indicators and will likely continue monitoring these handwashing indicators throughout the sustainable development goals.

Global monitoring efforts to assess the availability of water and soap in the household for handwashing creates opportunities to test how handwashing proxy measures from large household surveys are associated with child diarrhea. Initial work has been conducted in five countries in Sub-Saharan Africa [18]. The study reported that the handwashing proxy was not associated with child diarrhea in Ethiopia and Ghana while some associations were found in Malawi, Sierra Leone, and Zimbabwe [18]. The present study built on this study by expanding the geographic scope to 25 countries in Sub-Saharan Africa with the most recent DHS and MICS datasets and developing a handwashing ladder, which indicates a progressive improvement in access to water and soap at the handwashing place in the household. The main objective was to examine if the handwashing ladder is associated with the two-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 & 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 (USAID) and low- and middle-income countries to collect nationally representative household data on many health-related indicators [19]. Another large household survey, MICS, has been conducted by UNICEF since 1995 to facilitate global efforts to improve the lives of children and women [20]. DHS and MICS select nationally representative survey respondents by employing a stratified two-stage cluster sampling design [21]. Each country is typically stratified by type of residence (urban or rural) and each sub-country region [21]. 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 [21]. The list of DHS/MICS countries and total number of eligible children under five years included in this study is summarized in Table 1. After conducting the listwise deletion, the proportion of eligible children included in the analysis ranged from 70.1% in Nigeria to 96.0% in Ethiopia and Zimbabwe. Datasets of DHS and MICS are publicly available without any personally identifiable information, and the Institutional Review Board at the George Washington University determined that this study is not human subject research.

(Table 1)

Variables

The main independent variable for this study was the handwashing ladder, representing four conditions of a handwashing place in the household. During the data collection, the presence of a handwashing 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 handwashing 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 handwashing 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 handwashing place in the household (none); 2) presence of a handwashing place only (HW place only); 3) presence of a handwashing place with water or soap (incomplete); and 4) presence of a handwashing 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. 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 [22]. DHS and MICS includes the wealth index in each dataset, but this index has been constructed with types of drinking water sources and sanitation facilities [23]. To exclude water and sanitation variables as part of the wealth measurement, a new wealth quintile was constructed with 14 types of household assets using a principal component analysis. This study used the two-week prevalence of child diarrhea as the dependent variables (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 handwashing ladder and child diarrhea in each country by the chi-square test. The two-week prevalence of child diarrhea for each ladder component was estimated and presented by using a geographic information system (GIS). Multivariate analyses were also performed for each country by using the generalized linear model (GLM) with Poisson family and log link functions to estimate the prevalence ratio of child diarrhea [24]. If the variance inflation factor (VIF) was higher than 5 for any independent variable, it was removed from the multivariate model for the issue of multicollinearity. The analysis was adjusted for the complex survey design of DHS and MICS for the country level analysis.

This study also combined datasets from 25 countries to examine how the hygiene ladder was associated with child diarrhea in the SSA region and sub-populations after controlling for country-fixed effects and potential confounders. 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. 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 SSA region are presented in Appendix.

Results

The sample characteristics of diarrhea prevalence and the handwashing ladder are presented in Table 2 (also see Appendix Map 1, 2, 3). The number of survey respondents included in the analysis ranged from 2,188 in Swaziland to 19,879 in Nigeria. Over 20% of children in six countries (Burundi, Central African Republic, Chad, Malawi, Senegal, Uganda) had diarrhea in the last two weeks prior to data collection while the prevalence was less than 10% in Benin and Mali. The proportion of children who do not have access to a handwashing place in the household was higher than 50% in 15 countries, and it was highest in Ethiopia at 98.5%. This finding suggests that children or caregivers may not readily wash their hands with soap in these countries. In five countries (Chad, Ghana, Mauritania, Namibia, Swaziland), over 20% of children had access to a handwashing place with water and soap, but the overall proportion remained low.

(Table 2)

The two-week prevalence of child diarrhea by each component of the handwashing ladder is illustrated in Figure 1. The diarrhea prevalence was consistently higher than 20% across the handwashing ladder in Burundi, Chad, Malawi, and Uganda, and there was not a clear trend of reductions in the diarrhea prevalence by comparing a lower handwashing ladder (i.e., no handwashing place) with a higher handwashing ladder (i.e., handwashing place with water and soap). One exception was Namibia where the diarrhea

prevalence progressively declined by moving up the hygiene ladder from no handwashing place (26.06%), handwashing place only (20.71%), handwashing place with water or soap (19.23%), to handwashing place with water and soap (16.05%). There was a significant association between the handwashing ladder and child diarrhea ($p<0.05$) in seven countries (Benin, Mozambique, Namibia, Nigeria, Senegal, Togo, Zimbabwe), suggesting that the handwashing ladder may be a useful explanatory variable of child diarrhea in these SSA countries.

(Figure 1)

In 12 countries (Benin, Burkina Faso, Comoros, DRC, Cote'dIvoire, Ghana, Guinea, Mauritania, Mozambique, Senegal, Sierra Leone, Swaziland), children whose household had access to a place for handwashing with water and soap had higher diarrhea prevalence than those children in households without a place for handwashing. Although the difference of diarrhea prevalence is small (Appendix Table 1), this finding suggests that availability of water and soap at a handwashing place in the household does not necessarily translate to a reduction in the risk of diarrhea.

The results of multivariate analysis are presented in Figure 2. In most of the countries, there was not a significant difference in the diarrhea prevalence between children living in households that had a handwashing place with water and soap and children living in households without a handwashing place. In Chad and Mauritania, having a basic handwashing 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 ($p<0.01$). Thus, the direction and strength of

association between the hygiene ladder and child diarrhea can differ by countries after controlling for confounders.

(Figure 2)

(Figure 3)

Table 3 presents the results of a pooled data analysis after controlling for the country-fixed effects. The diarrhea prevalence among children who have access to a handwashing place with water and soap was 5% lower than that of children without a handwashing place in Sub-Saharan Africa ($p<0.05$). However, the presence of a handwashing place without or limited handwashing materials was associated with 5% higher diarrhea prevalence than that of children without a handwashing place.

(Table 3)

For the sub-population analysis, a significant protective effect was found for children who lived in households having a basic handwashing station in Central Africa, Southern Africa, males, and urban residents. The largest protective effect was found in Southern Africa where the presence of water and soap at a handwashing place was associated with a 22% lower prevalence of child diarrhea, compared to that of children without any handwashing place in the household ($p<0.05$).

After controlling for potential confounders and country-fixed effects, the diarrhea prevalence among children with a handwashing station with water and soap was no longer significantly different from that of children without a handwashing place in the household (Table 4). Having a handwashing place without or limited handwashing 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 estimated to be 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 ($p<0.001$). These findings suggest that water and sanitation ladders are useful to demonstrate the health benefits of climbing up the ladders while the handwashing ladder does not present similar empirical evidence. A water collection time of greater than 30 minutes was also associated with a 7% higher diarrhea prevalence than that of children whose families take less than 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 child diarrhea. More specifically, female children were associated with 6% lower diarrhea prevalence than that of male children ($p<0.001$). Compared to infants, children who are 1 year old (12 to 23 months) were associated with 39% higher diarrhea prevalence ($p<0.001$) while older children were associated with lower diarrhea prevalence. 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 did not have any formal education. However, maternal education of at least some primary education was associated with a 5% higher prevalence of child diarrhea ($p<0.001$), suggesting that incomplete primary education may not provide

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

(Table 4)

Discussion

This study examined if handwashing proxy measures in large household surveys were associated with child diarrhea in 25 countries in Sub-Saharan Africa. The analysis revealed that the handwashing ladder was not associated with child diarrhea in most of the countries. This finding is in accordance with other studies in Sub-Saharan Africa that reported a limited or lack of association between handwashing proxy measures and child health outcomes [18, 25].

A varying level of strength and direction of association between the handwashing ladder and child diarrhea in 25 countries highlighted the need for addressing unique contextual factors in each country. Our pooled data analysis controlled for such country-fixed effects and suggested that the presence of handwashing 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 handwashing 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.

In the pooled multivariate analysis, the diarrhea prevalence of children who have access to a handwashing place without or with limited handwashing materials was found to be significantly higher than that of children without a handwashing station in the household. While the exact reason for this finding remains unclear, children without a handwashing 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 handwashing without having a defined location for handwashing [26]. Accordingly, the cultural norm or custom of handwashing behaviors largely vary between countries in sub-Saharan Africa.

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 [27]. 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 [27]. 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 [28, 29]. Thus, 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 handwashing facilities. Although the availability of water and soap

may not always translate into handwashing with soap, physical facilities serve as an important behavioral cue and influence people's planning, habits, and motivations for handwashing behaviors [30]. In western Kenya, the presence of soap for handwashing was found to be associated with a reduced risk of child diarrhea [25]. Empirical research in Bangladesh also suggested that older residents of the household can contribute to reducing the risk of child diarrhea through their handwashing practices at critical moments, such as before cooking and after defecation [31]. The presence of a handwashing station with water and soap in the household therefore can facilitate older household members' handwashing 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 handwashing materials used, due to limited data availability. While the handwashing ladder contributed to assessing the availability of handwashing 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 handwashing station for disease prevention purposes as a possible scenario of reverse causation. 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 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 [23]. 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 handwashing ladder and child diarrhea.

Future studies should examine which factors are associated with presence of a handwashing place with water and soap in low- and middle-income countries. Some preliminary work has already been conducted in the recent review of handwashing proxy measurement in DHS and MICS, exploring the proportion of households with a handwashing station with water and soap by household heads' educational attainment, household wealth levels, and type of residence [32]. Additional studies could provide further insights into which factors facilitate the adoption of handwashing stations in the household. DHS and MICS also allow future research to examine the progress of increasing access to handwashing facilities over time in low- and middle-income countries. By using empirical evidence collected from nationally representative household surveys, handwashing with soap can be effectively promoted worldwide.

Conclusions

The present study examined the association between the handwashing 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 handwashing station with water and soap on child diarrhea. Handwashing practices by older residents of the household are likely to account for this health benefit to children under the age of five. Additional evidence remains essential to understand how to better motivate people to wash their hands with soap. Reliable and valid measurement of handwashing behaviors at a large scale is a very difficult undertaking. The handwashing proxy measure collected in large household surveys, however, is an important first step for monitoring and promoting handwashing with soap globally.

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

Table 1. DHS and MICS included in this study.

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'dIvoire	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
SSA region	16.38	62.04	14.85	11.15	11.96

Table 2. Two-week prevalence of child diarrhea and distribution of the handwashing ladder (%). Notes: *HW* = handwashing. *Incomplete* = water or soap is present at the HW place. *Basic* = both water and soap are present at the HW place.

Sub-population groups	HW place only	Incomplete	Basic
SSA 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)

Table 3. Pooled prevalence ratio of child diarrhea by handwashing ladders in sub-populations. Notes: The model adjusted for country and year fixed effects.

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 over 30 minutes (REF: <= 30)	1.07 (1.05, 1.10)***
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 to 23 months	1.39 (1.35, 1.43)***
24 to 35 months	0.95 (0.92, 0.98)**
36 to 47 months	0.60 (0.57, 0.62)***
48 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)*

Notes1: *p<0.05 **p<0.01 ***p<0.001

Notes2: The model controlled for country fixed-effects and the month of data collection.

Figures

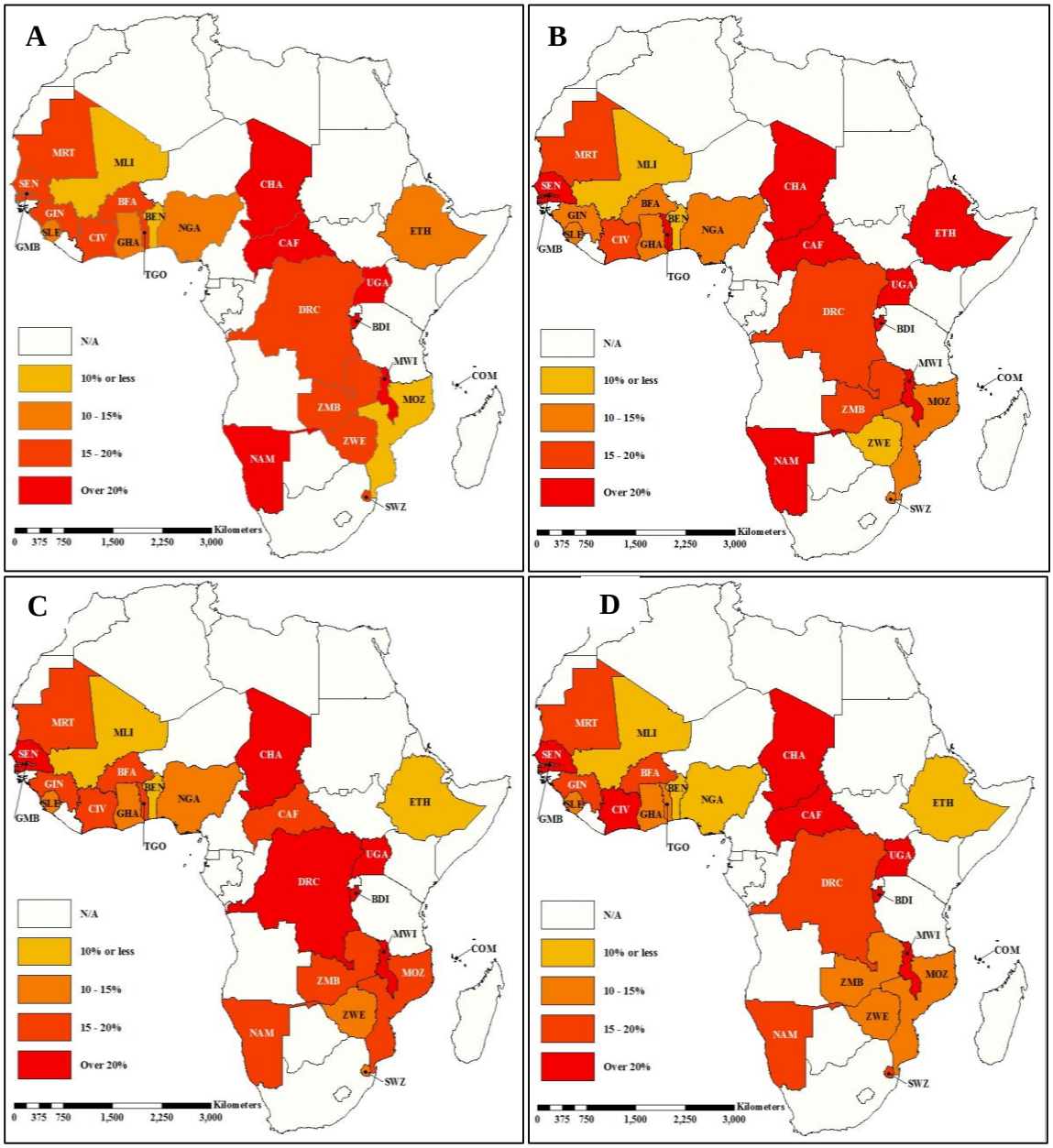


Figure 1. Two-week prevalence of child diarrhea by the handwashing ladder (A = No handwashing place; B = Handwashing place only; C = Handwashing place with water or soap; D = Handwashing place with water and soap).

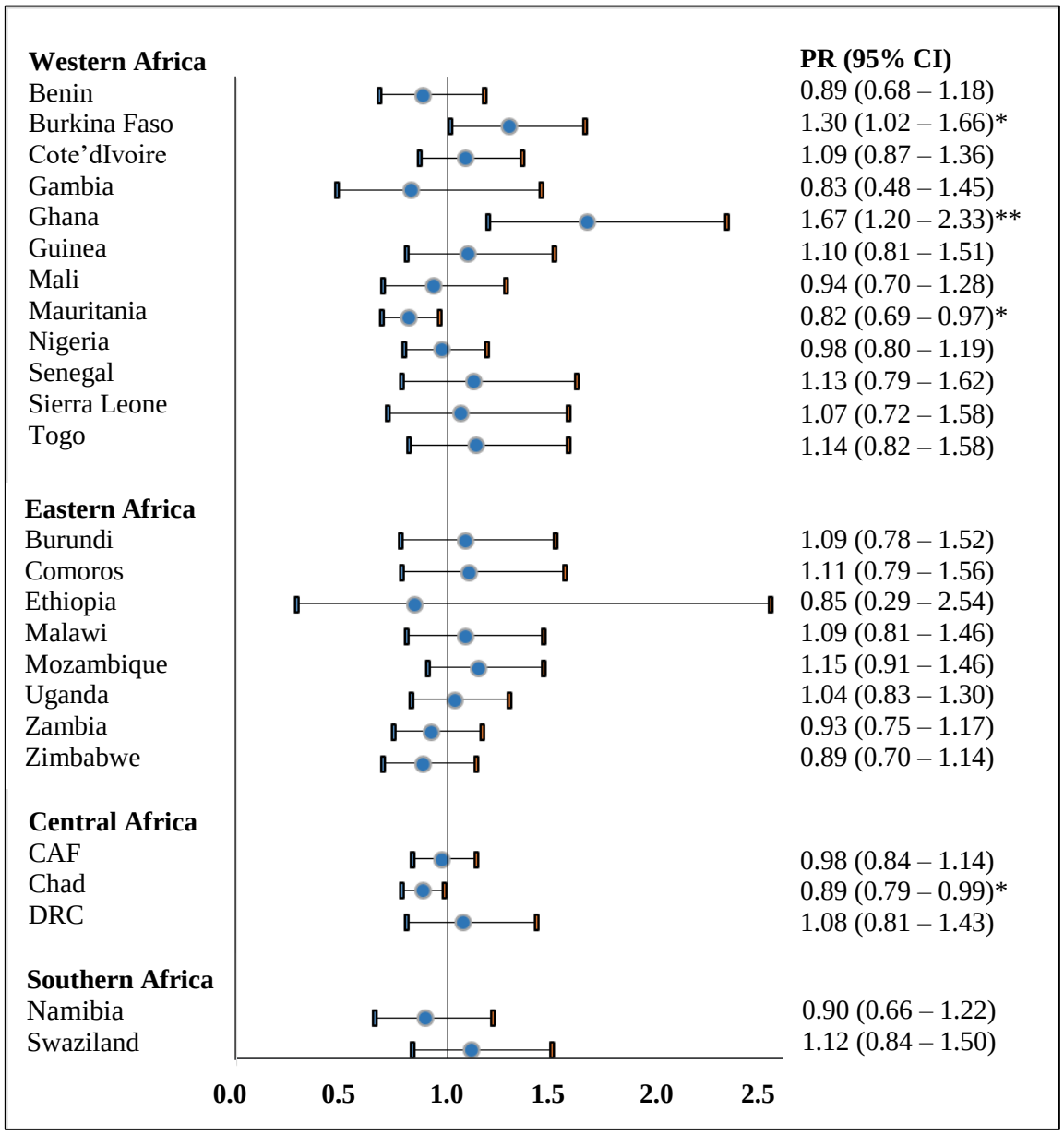


Figure 2. Adjusted prevalence ratios (PR) of child diarrhea comparing children who do not have a handwashing place and children who have access to a handwashing place with water and soap. Notes: *p<0.05 **p<0.01 CAF = Central African Republic DRC = Congo Democratic Republic

Appendices:

Regression equations for multivariate analyses

Country-level analysis

For each country, multivariate regression analyses were performed with the generalized linear model (GLM) with Poisson family and log link functions. The regression equation is

$$\ln\{E(y)\} = \beta 0 + \beta 1HW + \beta 2wat + \beta 3time + \beta 4sani + \beta 5fe + \beta 6age + \beta 7rural + \beta 8edu + \beta 9mem + \beta 10room + \beta 11region + \beta 12wealth + \beta 13mon \quad y \sim Poisson,$$

where $\beta 0$ represents the intercept, HW is a handwashing ladder (Ref = no HW place, 1 = HW place only, 2 = HW place with water or soap, 3 = HW place with water and soap), wat is a water ladder (Ref = surface water, 1 = Unimproved, 2 = Other improved, 3 = Piped water on premise), $time$ represents water collection time greater than 30 minutes (Ref = < 30 minutes), $sani$ is a sanitation ladder (Ref = open defecation, 1 = unimproved, 2 = shared, 3 = improved), fe represents female children (Ref = male children), age is child age (Ref = 0-11 months, 1 = 12 – 23 months, 2 = 24-35 months, 3 = 36-47 months, 4 = 48-59 months), $rural$ represents rural residence (Ref = urban residence), edu represents maternal education (Ref = no formal education, 1 = primary education, 2 = secondary or higher, 3 = religious school), mem represents the number of household members, $rooms$ represent the number of sleeping rooms at home, $region$ represents sub-national regions, $wealth$ represents the wealth quintile (Ref = poorest, 1 = poorer, 2

= middle, 3 = richer, 4 = richest), mon represents the month of data collection, and ε is an error term.

Based on the estimation of the variance inflation factor, *the water ladder* was removed from the regression model of Benin, Central African Republic (CAR), Chad, Comoros, Cote d'Ivoire, Gambia, Mali, Mauritania, Namibia, Senegal and Zimbabwe. *The month of data collection* was removed from Burkina Faso, Burundi, CAR, Chad, Cote d'Ivoire, Gambia, Guinea, Mali, Mauritania, Namibia, Senegal, *The sanitation ladder* was removed from Burundi, Comoros, and Gambia. *The region* was removed from Burundi, Congo Democratic Republic, and Togo. *The wealth quintile* was removed from Guinea. *The maternal education* was removed from Zimbabwe.

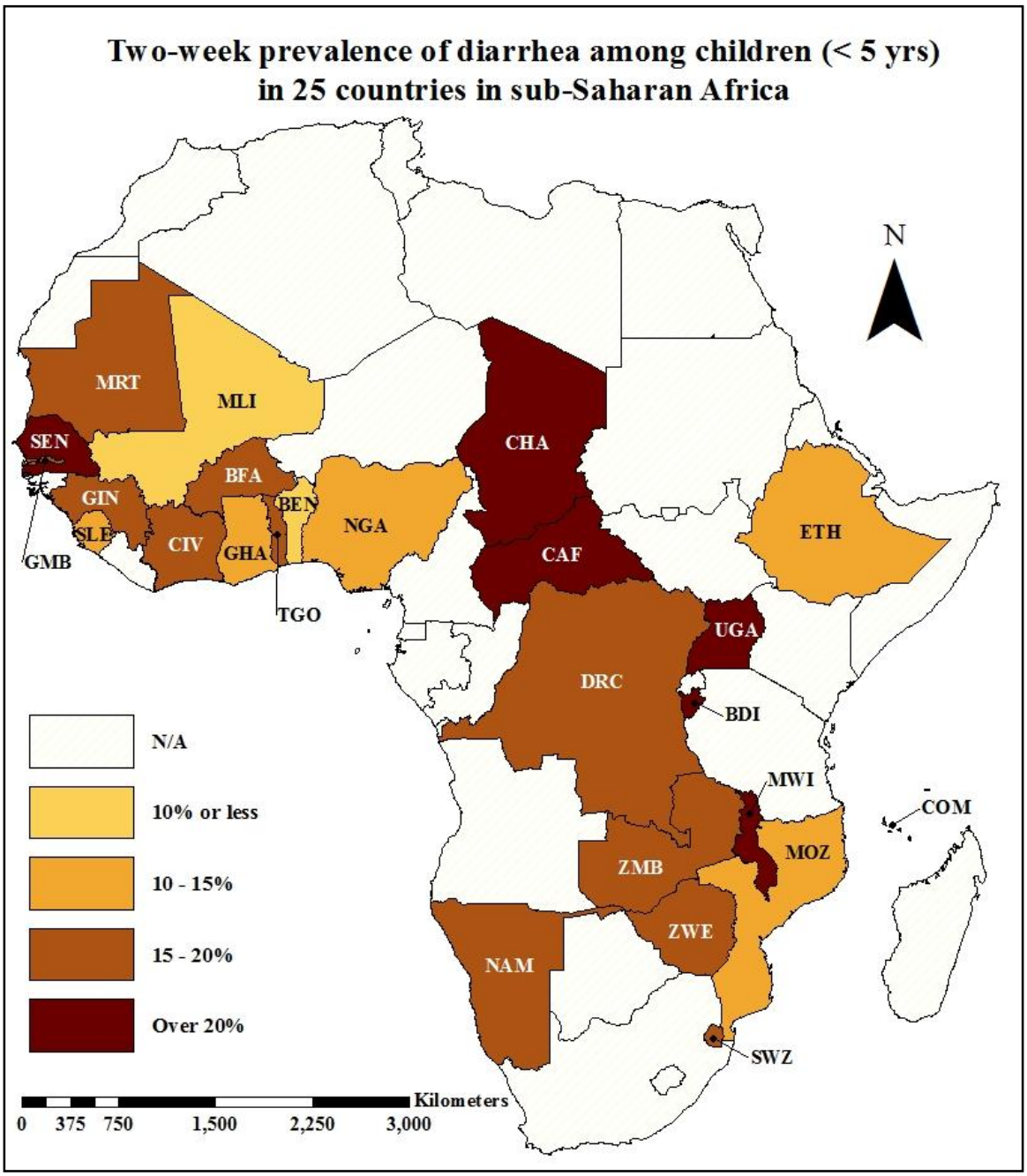
Pooled analysis

For the multivariate pooled analysis, the regression equation is

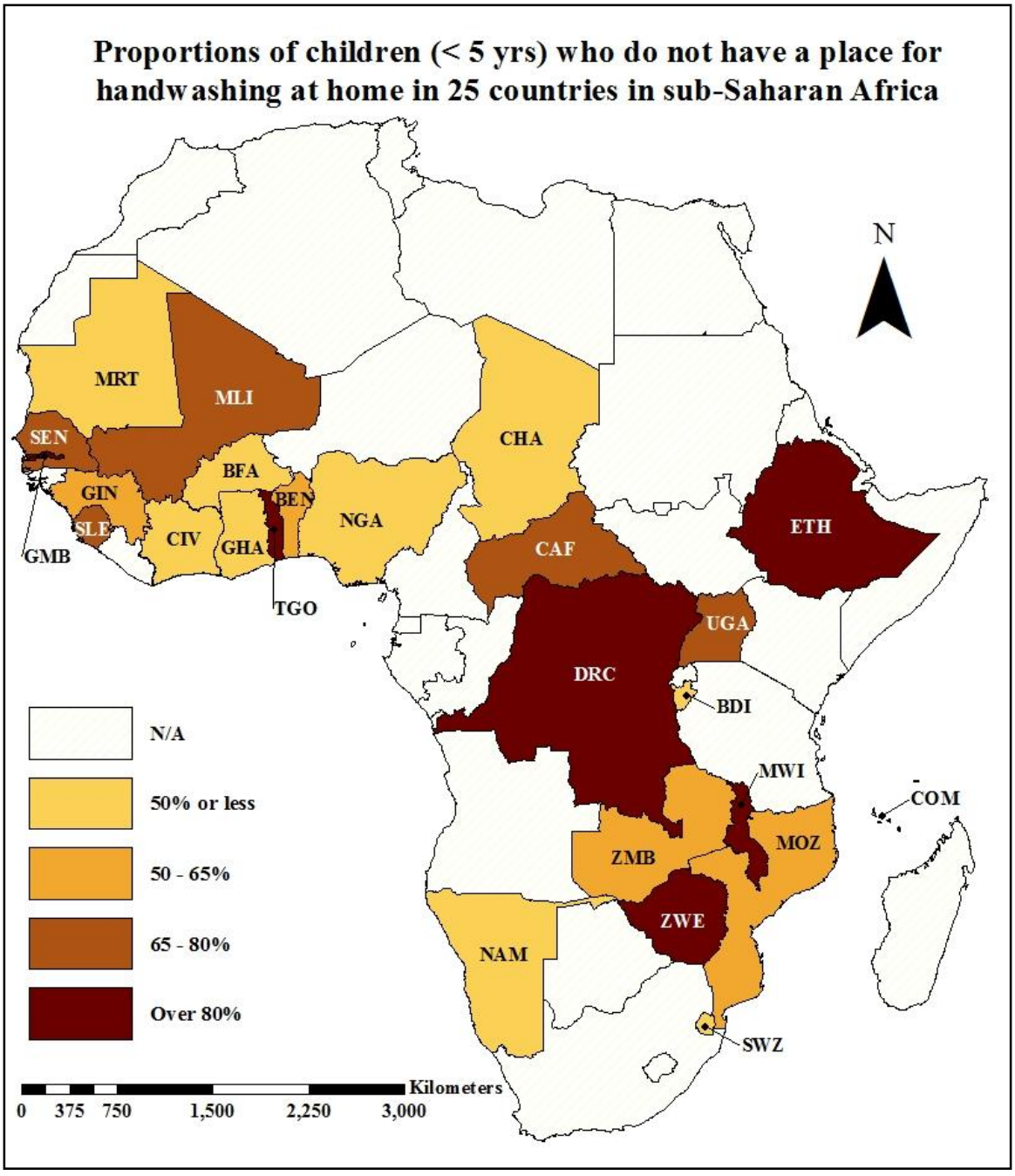
$$\ln\{E(y)\} = \beta 0 + \beta 1HW + \beta 2wat + \beta 3time + \beta 4sani + \beta 5fe + \beta 6age + \beta 7rural + \beta 8edu + \beta 9mem + \beta 10room + \beta 11country + \beta 12mon \quad y \sim Poisson,$$

where *country* represents 25 sub-Saharan African countries in this study (Ref = Benin). The other variables are the same as the country-level analysis.

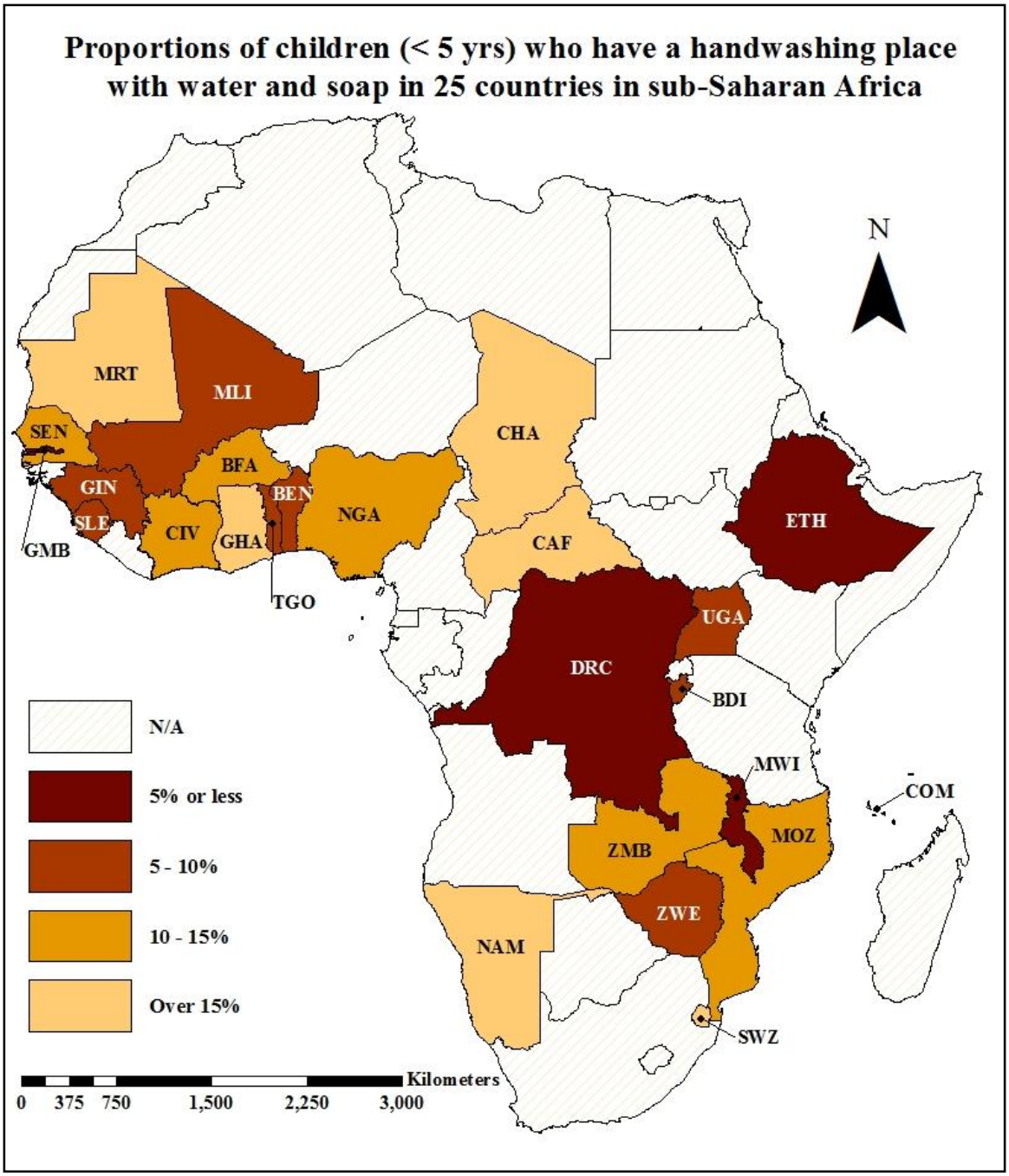
Supplemental Maps



Supplemental map 1 (Figure 3.3). Two-week prevalence of diarrhea among children under five years of age in 25 countries in Sub-Saharan Africa.



Supplemental map 2 (Figure 3.4). Proportions of children who do not have a place for handwashing at home in 25 countries in Sub-Saharan Africa.



Supplemental map 3 (Figure 3.5). Proportions of children who have a handwashing place with water and soap in 25 countries in Sub-Saharan Africa.

Supplemental Table 1 (Table 3.5)

Supplemental Table 1. Two-week prevalence of child diarrhea by the handwashing ladder

Country	No HW	Only HW	Incomplete	Basic	F	p-value
Benin	5.79%	9.33%	7.19%	5.99%	7.11	**0.0001**
Burkina Faso	16.07%	14.65%	15.47%	18.87%	2.57	0.0547
Burundi	25.26%	25.15%	26.68%	23.38%	0.31	0.8102
Central African Republic	24.13%	20.72%	18.09%	22.36%	1.53	0.2069
Chad	25.30%	23.29%	24.58%	22.50%	1.31	0.2711
Comoros	14.27%	19.16%	16.76%	18.82%	1.57	0.1990
Congo Democratic Republic	16.38%	17.30%	21.66%	17.08%	1.25	0.2883
Cote'dIvoire	18.45%	17.62%	16.93%	20.26%	0.60	0.6095
Ethiopia	13.53%	29.44%	8.23%	8.84%	2.45	0.0738
Gambia	17.52%	30.85%	16.92%	16.62%	1.51	0.2151
Ghana	10.21%	13.79%	11.84%	11.91%	1.65	0.1795
Guinea	15.02%	13.89%	17.79%	15.51%	0.90	0.4367
Malawi	24.40%	28.19%	21.60%	21.64%	1.25	0.2899
Mali	9.03%	8.45%	5.49%	8.97%	2.21	0.0878
Mauritania	15.39%	17.78%	18.64%	16.11%	1.60	0.1890
Mozambique	9.63%	13.14%	15.18%	12.16%	6.38	**0.0004**
Namibia	26.06%	20.71%	19.23%	16.05%	5.01	**0.0021**
Nigeria	11.15%	10.32%	10.66%	7.53%	4.70	**0.0032**
Senegal	18.27%	29.43%	25.77%	21.85%	6.30	**0.0010**
Sierra Leone	11.83%	10.98%	14.94%	11.98%	0.63	0.5952
Swaziland	17.66%	14.73%	14.84%	18.50%	1.17	0.3206
Togo	15.05%	23.14%	19.50%	12.65%	3.43	**0.0184**
Uganda	22.93%	25.47%	27.09%	20.17%	2.05	0.1050
Zambia	16.10%	17.51%	17.66%	14.59%	1.29	0.2776
Zimbabwe	16.17%	9.70%	13.33%	11.30%	5.53	**0.0009**

Note: A chi-square test was used for this analysis.

Chapter 4:

Geographical distributions of high-risk water, sanitation, and hygiene practices and their association with child diarrhea in Uganda

Introduction

Globally, almost 1,600 children under five years of age die from diarrhea every day [1]. In 2013, limited access to water, sanitation, and hygiene (WASH) was estimated to account for 58% of diarrhea-induced mortality or nearly 840,000 deaths in low and middle-income countries [2]. Diarrhea particularly affects children in the sub-Saharan African (SSA) region [3]. The under-five mortality rate from diarrheal diseases was the highest in SSA at 214 deaths per 100,000 children, compared to that of South Asia at 86 deaths per 100,000 [4].

The etiology and transmission mechanism of diarrhea have been elucidated in previous research [5, 6]. Diarrhea can be caused by bacteria, enteric viruses, protozoa, and helminths with varying levels of severity and symptoms [5]; rotavirus is the most prevalent etiological agent globally [7]. The fecal-oral transmission model suggests that those infectious micro-organisms in people's stools enter human bodies through the contact or consumption of contaminated fluids, foods, flies, fingers, and fields [6]. Improving water supply (i.e. access), water quality, sanitation facilities, and handwashing behaviors can interrupt this transmission cycle [8] and reduce the risk of diarrhea by an estimated 17 to 48% [9, 10].

Global efforts under the Millennium Development Goals (MDGs) have rapidly increased household access to improved drinking water sources and improved sanitation [11]. Since 1990, 2.6 and 2.1 billion people worldwide have obtained access to improved water and sanitation, respectively [11]. Although improved water sources do not always provide safe drinking water [12, 13, 14], empirical evidence suggested that improved drinking water and improved sanitation are both associated with a lower risk of child diarrhea [15].

Despite major improvements in water and sanitation practices globally, a large number of individuals still engage in unsafe WASH practices that can increase diarrheal risks. Globally, 189 million people still rely on surface water as the main drinking water source, and 946 million people practice open defecation [11]. Approximately 44% of the global population must fetch water outside of the household, and water collection time has been found to be positively associated with an increased risk of child diarrhea [16]. When households are required to spend more than 30 minutes to collect water, an adequate amount of water for basic needs (e.g., handwashing) may not be collected [17]. The prevalence of handwashing with soap after using the toilet or contacting human excreta is also estimated to be 19% globally [18]. Empirical evidence suggests that national estimates of water and sanitation coverage may mask large geographical disparities within each country [19]. Exploring the geographical distribution of WASH behaviors is therefore vital to identify vulnerable populations and better target investments in the WASH sector.

There is a limited body of evidence on the concentration of high-risk WASH practices in small geographical units and the population who bears the highest burden from limited WASH. This study aimed to address these knowledge gaps by assessing geographic disparities in high-risk WASH conditions in Uganda. The high-risk WASH practices for this case study included: 1) drinking surface water without treatment, 2) open defecation, 3) absence of a place for handwashing in the household, and 4) water collection time greater than 30 minutes. To identify the population bearing the highest burden from poor WASH conditions, this study also develop the WASH Resource Index (WRI) as a proxy measure and estimate its association with two-week prevalence of child diarrhea. We hypothesized that high-risk WASH practices and the WRI are associated with child diarrhea after controlling for potential confounders.

Methods

Data Source

This study analyzed data from the Uganda Demographic and Health Survey (DHS) 2011, a nationally representative household survey funded by the United States Agency for International Development [20]. Since 1984, the DHS has been conducted in many low- and middle-income countries to obtain data on vital statistics and population health measures [21]. To ensure the representativeness of the population in the survey, the DHS Program employs the stratified two-stage sampling method for sample selection [21]. A country is typically stratified by type of residence (urban/rural) and sub-national regions to form strata. In the first stage of sampling, primary sampling units or clusters (e.g., a city block, village) will be selected from each stratum based on probability proportional

to size. In the second stage, households will be systematically selected by referring to the household listing obtained in each cluster. This sampling strategy and high response rates contribute to a high level of generalizability of study findings [21]. For this study, data on 7,208 children under the age of five were available, and 7,019 (97.4%) were included for analyses. Given that DHS datasets are publicly available without any private information, the IRB at the George Washington University determined that this study is not human subject research.

Variables

The independent variables of this study included: 1) drinking surface water without any effective treatment; 2) open defecation; 3) absence of a place for handwashing in the household as a proxy for lack of handwashing with soap [22]; 4) water collection time greater than 30 minutes; 5) an additive index of these four high-risk WASH practices; and 6) the WASH Resource Index. Each of the high-risk WASH practices was a binary variable (1 = Yes, 0 = No). If households mentioned river, stream, pond, lake, or dam as the main drinking water source and did not report to make the water safer with effective methods (e.g., boiling, using chlorine, water filter) in the survey, they were regarded as drinking surface water without any treatment. Open defecation was measured with the question concerning the type of sanitation facilities that household members usually use, and households reporting no facility, bush, or field were counted as practicing this high-risk behavior. The handwashing variable was the only variable measured by direct observation. If the interviewer did not observe a specific location for handwashing in the home, yard, or plot during the data collection, households were considered as having no

handwashing place. Self-reported water collection time was categorized into two timeframes (1 = greater than 30 minutes, 0 = 30 minutes or less). All of these high-risk WASH practices were summed to create an additive index.

The WASH Resource Index (WRI) was constructed with the main source of drinking water, types of household sanitation facilities, practice of sharing sanitation facilities, handwashing materials in the household, and water collection time. All of the answer options in these variables except for "don't know" or missing were included as indicator variables. A principal component analysis was used to summarize these WASH resource indicators into one summary measure – the methods used are the same as those for developing a wealth index in the DHS [23]. Based on the WRI scores, the WASH quintiles were constructed to classify households with the categories of WASH poorest, poorer, middle, richer, and richest.

Other independent variables included urban or rural residence, maternal education, and household wealth levels. The wealth index in the DHS was constructed with water and sanitation variables, which can introduce a bias to the estimated association between the WASH Resource Index and child diarrhea. Although empirical evidence suggested that wealth indices with or without water supply and sanitation variables are highly correlated and produce mostly concordant results in quintile assignments [24], the present study developed a wealth index without water and sanitation variables. The index included 14 types of household assets other than WASH-related assets to ensure the theoretical

distinction. Control variables for the analysis were child age, child sex, sub-country regions, and month of the interview as a proxy for season.

Statistical and Spatial Analysis

The prevalence of the aforementioned high-risk WASH practices, indices, and child diarrhea was estimated at the household level and at the cluster level. Each cluster consists of 2 to 38 households and represents the average value of these households. By using all of the clusters as data points, descriptive analyses were displayed on maps. This study also examined the correlation of an additive index of high-risk WASH practices and the WRI with child diarrhea to assess the performance of WRI as a proxy measure of WASH-related burden at the cluster level.

This study also conducted a hot spot analysis of high-risk WASH practices and child diarrhea. A hot spot analysis estimated the Getis-Ord Gi* statistic and z-scores to assess whether high-risk WASH practices and child diarrhea are geographically clustered [25]. More specifically, this analytical approach compared the local mean (e.g., average prevalence of open defecation for a few clusters including a cluster of interest) with the global mean (e.g., average prevalence of open defecation for all clusters). If the local mean was statistically higher or lower than the global mean, a given cluster was classified as a hot spot or a cold spot. The boundary of hot and cold spots was determined by the fixed distance method by which clusters within a critical distance form a bundle, and the influence from other clusters outside of this bundle will be zero [26].

Bivariate and multivariate associations between independent variables and child diarrhea were examined by the generalized linear model (GLM) with Poisson family and log link. For the multivariate analysis, a nested regression model was employed with the WRI as the main independent variable. The zero-order model included the WRI and control variables. The second model added type of residence (urban/rural) to the zero order model. The third model added maternal education to the zero-order model. The fourth model added wealth quintiles to the zero-order model. The fifth model added all of the independent variables. By constructing multivariate models as a nested structure, the moderation effect of type of residence, maternal education, and wealth levels on the association between the WASH Resource Index and child diarrhea can be examined. Statistical analyses were adjusted for the complex survey design of the DHS, and fit statistics were estimated with adjusted Wald tests to identify the most parsimonious model.

Results

Descriptive statistics of sociodemographic characteristics and high-risk WASH practices are presented in Table 1. Approximately 6% and 11% of children lived in households that reported to drink untreated surface water and engage in open defecation, respectively. The majority of children did not have a location for handwashing available for the household, and 41.3% lived in a household that reported to spend more than 30 minutes for water collection. Almost one in four children (24.1%) were reported to have diarrhea during the past two weeks.

(Table 1)

According to the newly constructed WRI, 6.1% of children belonged to the WASH poorest group, bearing the highest burden from inadequate access to WASH resources. The largest proportion of children was in the WASH poorer group at 38.6%. Over 85% of children lived in rural areas, and 14.4% of mothers did not have any formal education in total. Male and female children were almost equally represented in this study.

Spatial analysis

The geographical distribution of drinking untreated surface water, open defecation, lack of a handwashing place, water collection time over 30 minutes at the cluster level is presented in Figure 1. In most of the clusters, the proportion of children who were exposed to untreated surface water was below 15%, but multiple clusters in Karamoja and West Nile regions had the prevalence of over 60%. Geographically distant regions from Kampala also included more clusters with a higher prevalence of this high-risk practice than other regions. Many clusters in Karamoja region were in dark red (>60%) for open defecation, suggesting that a large proportion of children did not have access to sanitation facilities. A few clusters with the prevalence of over 60% are also located in North and West Nile regions and an island on Lake Victoria. In South West region, all of the clusters except for one were estimated to have an open defecation prevalence lower than 15%. Compared to other high-risk WASH practices, absence of handwashing place for the household was prevalent across many sub-country regions. In many clusters, over 80% of children did not have immediate access to a handwashing place. In the western part of Central 1 region, however, a series of clusters had the prevalence below 20%. The map displays that a large proportion of children lived in the household spending over 30

minutes to obtain their drinking water without a clear geographical concentration of the practice.

(Figure 1)

Figure 2 displays the average number of high-risk WASH practices, self-reported water collection time of over 60 minutes, the average of WRI quintiles, and two-week prevalence of child diarrhea at the cluster level. Many clusters in Karamoja region were in dark red, so children in many communities were exposed to at least two high-risk WASH practices on average. The map also shows that compared to Central regions (Central 1 and Central 2), clusters in geographically distant regions, such as West Nile, North, and Western, had a higher number of high-risk WASH practices. The proportion of households that spend more than one hour to collect their drinking water was lower than 15% in the majority of clusters. At some clusters, however, over 60% of households were estimated to engage in this practice without a clear geographical concentration. A series of clusters with the average child diarrhea prevalence of 30 to 45% were present in Eastern and East Central regions, but every region included multiple clusters with this level of diarrhea prevalence. Karamoja included many clusters with a high prevalence of drinking untreated surface water, open defecation, lack of handwashing place, and water collection time of over 30 minutes, but a fewer number of clusters had a high level of child diarrhea in the region.

(Figure 2)

The results of a hotspot spot analysis on high-risk WASH practices are presented in Figure 3. Kampala was consistently classified as a cold spot (z-score < -1.96) for all of the high-risk WASH practices in this study. Hot spots of drinking surface water without

effective treatment (z-score > 1.96) were located in West Nile, Western, and Karamoja regions. All of the clusters in Karamoja region and a few clusters from West Nile, North, and Eastern regions represent hot spots of open defecation. Western, North, Eastern, and Karamoja regions also included hot spots of lack of handwashing place in the household. Hot spots of time-consuming water collection labor were located in most of the sub-country regions except for Southwest.

(Figure 3)

Figure 4 presents the hot spots and cold spots of the average number of high-risk WASH practices, water collection over 60 minutes, WRI quintiles, and two-week prevalence of child diarrhea at the cluster level. The analysis suggests that communities and villages in Karamoja, North, West Nile, and Eastern regions engage in a significantly higher average number of high-risk WASH practices than the global mean or the national average of 1.19. Hot spots of water collection time of greater than 60 minutes were mostly concentrated in the southern part of North region and the northern part of Karamoja region. Many clusters in Kampala and Central regions were highlighted as the hot spots of the average WRI quintiles, suggesting that households with higher or richer quintiles were clustered in these geographical areas. Hot spots of child diarrhea are clustered in Eastern and East Central regions, and cold spots were located in Karamoja, West Nile, Western, and Southwest regions. The results suggest that hot spots of high-risk WASH practices and child diarrhea do not overlap with each other. A few clusters located in northern part of Karamoja region were consistently classified as hot spots of high-risk WASH practices, but they were cold spots of child diarrhea.

(Figure 4)

Assessment of Water Resource Index (WRI)

A scatter plot matrix on the two-week prevalence of child diarrhea, the average number of high-risk WASH practices and the mean WASH quintiles from the calculated WRI at the cluster level is presented in Figure 5. The additive index of high-risk WASH practices and the WASH quintiles were both negatively associated with child diarrhea ($p<0.001$) without a clear linear relationship.

(Figure 5)

Based on the principal component analysis, the interpretability of the principal component in WRI was limited. A high negative correlation ($r = -0.86$) with the average number of high-risk WASH practices, however, suggests that children in higher quintiles of WRI (e.g., WASH Richest) may be exposed to a fewer number of high-risk WASH practices. Thus, the WRI quintiles can be a useful summary proxy measure of WASH-related burden from limited access to WASH resources at least in this context.

Bivariate & Multivariate analysis

In accordance with the findings from the spatial analysis, this study did not find a statistically significant bivariate association between high-risk WASH practices and child diarrhea (Table 2). Compared to the lowest quintile in the WRI, the highest quintile was associated with 24.9% lower prevalence ($p<0.05$). The WRI quintiles, however, were not significantly associated with child diarrhea.

(Table 2)

The results of a multivariate analysis at the household level are presented in Table 3. In Model 1, children in WASH Middle, Richer, and Richest quintiles were associated with

significantly lower diarrhea prevalence than that of WASH Poorest quintile by 20.0%, 21.0%, and 25.7%, respectively. Adding rural residence in Model 2, maternal education in Model 3, and wealth quintiles in Model 4 completely mediated the relationship between WRI quintiles and child diarrhea. The first three models suggested that moving up the WRI quintile is associated with a progressively lower prevalence of child diarrhea prevalence, but this trend was not detected in Model 4 and Model 5.

(Table 3)

Compared to Kampala, children in West Nile, Western and Southwest were consistently and significantly associated with lower diarrhea prevalence in all of the models. Child sex and rural residence were not associated with child diarrhea in multivariate models, but age was identified as a significant explanatory factor. One-year-old children were associated with significantly higher prevalence of child diarrhea than that of infants, but older children (>23 months) were associated with lower diarrhea prevalence. Maternal education and household wealth levels were also found to be significantly associated with lower child diarrhea. Based on the fit statistics, Model 3 was the most parsimonious model to examine child diarrhea prevalence in this study.

Discussion

This study conducted spatial and statistical analyses to assess how high-risk WASH practices—drinking surface water without any effective treatment, open defecation, lack of handwashing place, and water collection time of 30 minutes or more—were geographically distributed in Uganda and how these WASH factors were associated with two-week prevalence of child diarrhea. As a proxy measure of WASH-related burden

from limited access to WASH resources, this study also developed the WASH Resource Index and demonstrated a high correlation with the number of high-risk WASH practices. The study found that high-risk WASH practices and child diarrhea were clustered in different geographical areas at the cluster level. The multivariate analysis at the household level, however, demonstrated some protective effect of being in higher WASH quintiles, highlighting the importance of obtaining adequate access to safe drinking water, sanitation practice, and hand hygiene for diarrhea prevention.

The spatial analyses of high-risk WASH behaviors suggested that lack of a designated handwashing place for the household was particularly prevalent across the country. Handwashing behaviors can be shaped by many determinants including socio-demographic, psychosocial, and structural factors [27]. Accordingly, having a handwashing place with water and soap may not immediately translate to handwashing practices. Nonetheless, it remains vital to enhance access to handwashing resources for the household as a physical cue to the behavior [28]. An in-depth discussion on the behavioral determinants of handwashing with soap is beyond the scope of this paper, but the importance of access to infrastructure or technology to elicit handwashing behaviors has been well-recognized in literature [28, 29].

This study also revealed that a large proportion of households still report to spend more than 30 minutes to collect their drinking water although 70% of the Ugandan population is estimated to have access to improved sources of drinking water [20]. This finding suggests that people still bear a great deal of physical burden and opportunity costs of

carrying water from the source to the household every day. Further efforts to promote access to drinking water on premise are essential as time-consuming water collection labor is pertinent to child health, school education, and maternal health.

The spatial analysis suggested that high-risk WASH practices were clustered in Karamoja region while displaying a relatively low prevalence of child diarrhea. Poverty and maternal education could partially account for this finding. A further analysis of the data found that 78.8% of children in Karamoja region were from households in the poorest wealth quintile, and 64.0% of mothers had not received any formal education. Accordingly, people's ability to purchase and maintain WASH-related resources were probably limited in this region. Limited education to learn about diarrheal disease at school could have also rendered some mothers less cautious to detect children with diarrhea. Previous research suggested that child diarrhea was reported at increased rates in DHS by mothers with higher levels of education, which may also explain our findings [30].

A high prevalence of child diarrhea was found in the Eastern and Eastern Central regions despite a low concentration of high-risk WASH practices. A previous study in Uganda, which analyzed DHS data from 2000/2001, also suggested that these geographical areas had a higher prevalence of child diarrhea than other regions [31]. The same study mentioned political instability as a potentially influential factor of this finding [31]. The exact reasons for a high prevalence of child diarrhea in the Eastern region, however,

remain unclear. Additional research is necessary to identify the most influential determinants of child diarrhea in this region and reduce the burden of diarrheal diseases.

Although this study conducted a specific statistical method to develop the WRI, the WRI and the additive index of high-risk WASH behaviors produced mostly concordant results in their geographical distributions and correlations with child diarrhea. This finding suggests that the most vulnerable population with least access to WASH can be adequately identified with the additive index, which can be developed without a complex procedure. The WRI, however, has not been used to estimate the risk of other health outcomes, such as stunting, respiratory infections, and soil-transmitted helminths. The utility of the WRI in examining public health issues therefore can be further explored by future studies.

The present study included a number of limitations. First, all of the data in this study except for a handwashing place for the household were measured by self-reports, which may suffer from recall and reporting biases. Self-reported child diarrhea can be measured at different recall periods including 24 hours, two days, seven days, and two weeks [32]. Empirical evidence suggested that the one-week recall period can provide reasonable estimates of diarrhea prevalence without requiring a significant increase in sample size or producing reporting bias [32]. The major household surveys, including DHS and the Multiple Indicator Cluster Survey (MICS), however, still estimate two-week prevalence of child diarrhea, which may limit the reliability of the findings in this study. Second, the cross-sectional design of this study cannot establish the temporality of variables or rule

out the possibility of reverse causality. Due to severe cases of child diarrhea, households could have changed the source of their drinking water, improved sanitation practice, or created a handwashing place for disease prevention purposes. In this case, the relationship between the dependent and independent variables can be reversed. However, little empirical evidence exists to corroborate this possibility. Third, each cluster or primary sampling unit that was used to assess the geographical distribution of high-risk WASH behaviors included a varying number of households, which might not produce a reliable result. The prevalence of high-risk WASH practices estimated at the cluster level therefore needs to be assessed by aggregating some of the clusters to be more reliable. By conducting a hot spot analysis in which the mean prevalence of multiple clusters was compared with the mean prevalence of all clusters, this study minimized the risk of producing unreliable findings at the cluster level. Fourth, the month of data collection as a proxy measure for dry and rainy seasons might not fully control for the effect of seasonality. Lastly, stunting was not included as a potential confounder of the WRI and child diarrhea because it would severely reduce the sample size of this study. Empirical evidence suggested that stunting is associated with both WASH practices and child diarrhea [33, 34]. Future studies can estimate the independent effect of the WRI on child diarrhea more accurately by controlling for stunting.

Conclusion

This study revealed geographical disparities in access to varying WASH conditions and practices among Ugandan households. Large geographical differences in the prevalence of drinking untreated surface water, open defecation, absence of a place for handwashing,

and water collection labor were found. These high-risk WASH practices, however, were not found to be associated with child diarrhea, potentially due to recall and reporting biases. Future studies applying experimental designs and different recall periods of child diarrhea may provide useful insights into how high-risk WASH practices are associated with child morbidity and mortality. The potential utility of the WASH Resource Index can be also examined for different health outcomes than child diarrhea. While access to adequate WASH conditions need to be monitored at the national and global level, it is vital to address geographical disparities within each country to target the most vulnerable populations for greater investments.

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Variables	% of Children (n = 7,019)
High-risk WASH practices	
Drinking unsafe water	6.13
Open defecation	11.13
Absence of handwashing place	56.95
Water collection time >= 30 mins	41.30
Two-week prevalence of diarrhea	24.08
WASH Resource Index	
WASH Poorest	6.11
WASH Poorer	38.60
WASH Middle	26.18
WASH Richer	19.61
WASH Richest	9.50
Wealth quintiles	
Poorest	23.13
Poorer	23.17
Middle	20.39
Richer	17.93
Richest	15.38
Region	
Kampala	5.86
Central 1	9.69
Central 2	10.42
East Central	11.25
Eastern	17.02
North	9.18
Karamoja	3.82
West-Nile	5.90
Western	14.64
Southwest	12.21
Type of residence	
Urban	14.06
Rural	85.94
Maternal education	
No education	14.42
At least some primary	63.61
At least some secondary	18.36
Higher	3.61
Age of children	
Less than 12 months	22.09
12 - 23 months	19.99
24 - 35 months	20.14
36 - 47 months	19.32
48 - 59 months	18.47
Sex of children	
Male	49.88
Female	50.12

Table 1. Sociodemographic and WASH characteristics.

Variables	PR	Std. Err.	t	95% CI		df	F
High-risk WASH practices							
Drinking untreated surface water	0.879	0.998	-1.13	0.704	1.099	(1, 385)	1.28
Open defecation	1.151	0.099	1.64	0.972	1.363	(1, 385)	2.68
No handwashing place	0.892	0.050	-2.02	0.798	0.997	(1, 385)	4.09
Water collection time >=30 mins	1.096	0.061	1.64	0.982	1.223	(1, 385)	2.69
Water Resource Index quintiles						(4, 382)	1.30
WASH Poorer	0.858	0.088	-1.49	0.701	1.051		
WASH Middle	0.822	0.096	-1.68	0.654	1.034		
WASH Richer	0.881	0.105	-1.06	0.698	1.113		
WASH Richest	0.751*	0.103	-2.09	0.573	0.982		

Table 2. Unadjusted prevalence ratios (PR) of child diarrhea by high-risk WASH practices and WRI quintiles. Notes: *p<0.05, **p<0.01, ***p<0.001

	Model 1	Model 2	Model 3	Model 4	Model 5
WASH Resource Index					
(Ref = Poorest)					
WASH Poorer	0.853	0.856	0.871	0.890	0.897
WASH Middle	0.800*	0.828	0.830	0.881	0.880
WASH Richer	0.790*	0.806	0.824	0.858	0.866
WASH Richest	0.743*	0.779	0.820	0.863	0.888
Sub-country regions					
(Ref = Kampala)					
Central 1	0.769	0.653*	0.686*	0.625*	0.629**
Central 2	0.81	0.705*	0.723*	0.657**	0.657**
East Central	1.161	0.998	1.028	0.894	0.903
Eastern	0.995	0.851	0.877	0.705*	0.717*
North	0.861	0.742	0.745	0.590**	0.596**
Karamoja	0.703	0.608*	0.618*	0.473***	0.492**
West-Nile	0.640**	0.550***	0.552***	0.434***	0.439***
Western	0.691*	0.598**	0.610**	0.530***	0.536***
Southwest	0.479***	0.408***	0.417***	0.361***	0.365***
Child age					
(Ref = Less than 12 months)					
12 to 23 months	1.200**	1.199**	1.202**	1.214**	1.215**
24 to 35 months	0.710***	0.707***	0.707***	0.717***	0.715***
36 to 47 months	0.486***	0.487***	0.489***	0.490***	0.492***
48 to 59 months	0.343***	0.343***	0.340***	0.345***	0.344***
Female (Ref = Male)	0.921	0.922	0.918	0.922	0.921
Rural residence (Ref = Urban)		1.200			0.955
Maternal education					
(Ref = No educ)					
Primary			1.020		1.054
Secondary			0.798*		0.880
Higher			0.503***		0.589*
Wealth quintiles (Ref = Poorest)					
Poorer				0.874	0.885
Middle				0.756**	0.766**
Richer				0.783**	0.820*
Richest				0.560***	0.630**
Constant	0.663*	0.648*	0.754	0.972	0.963
Model fit					
F-statistic	17.93	17.81	18.85	18.03	17.45
df	(26, 360)	(27, 359)	(29, 357)	(30, 356)	(34, 352)

Table 3. Adjusted Prevalence ratios of child diarrhea by GLM with Poisson Family and Log link function. Note: All models controlled for the month of interview, number of household members, and rooms used for sleeping. *p<0.05 **p<0.01 ***p<0.001

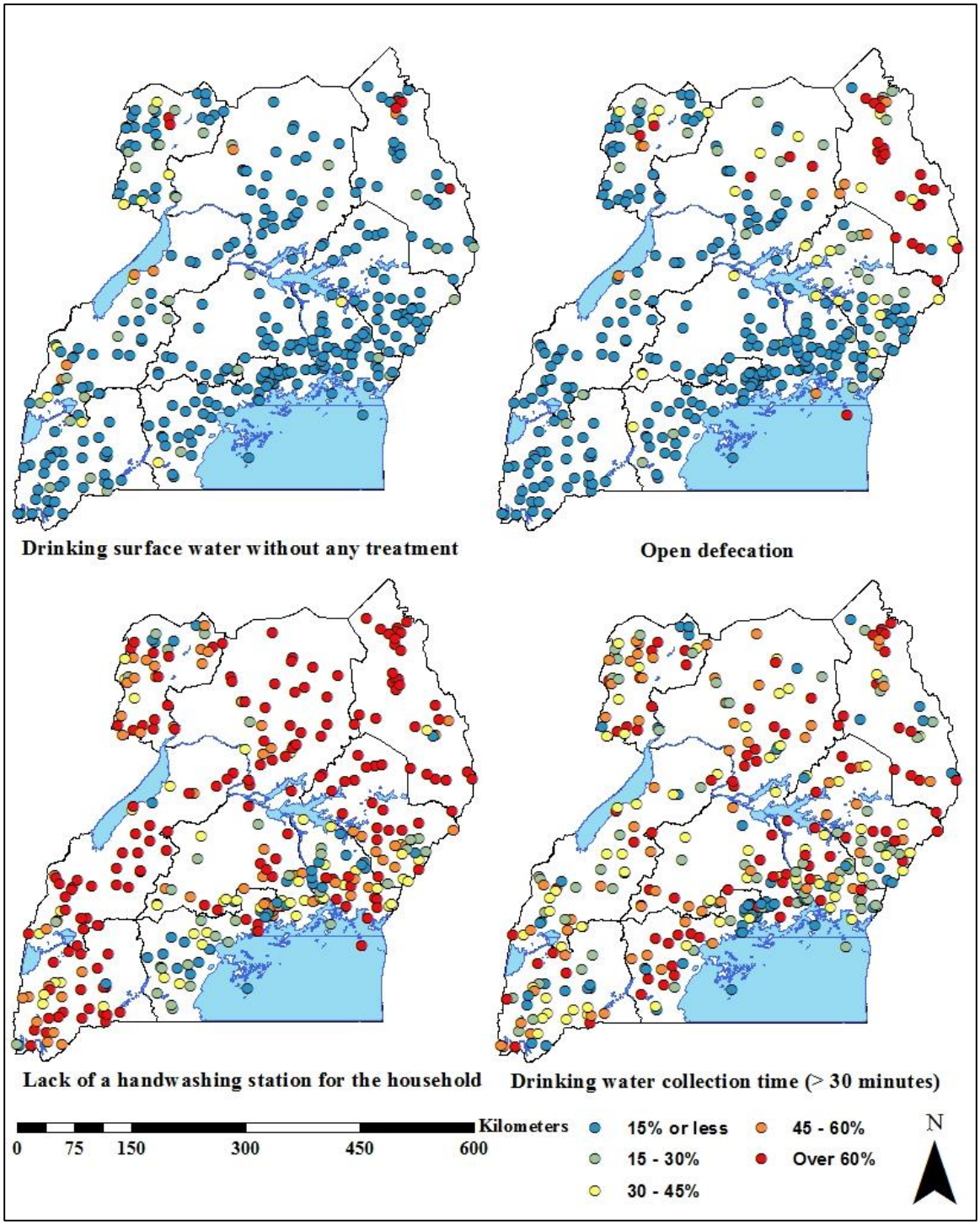

Figure 1. Geographical distributions of high-risk WASH practices at the cluster level in Uganda.

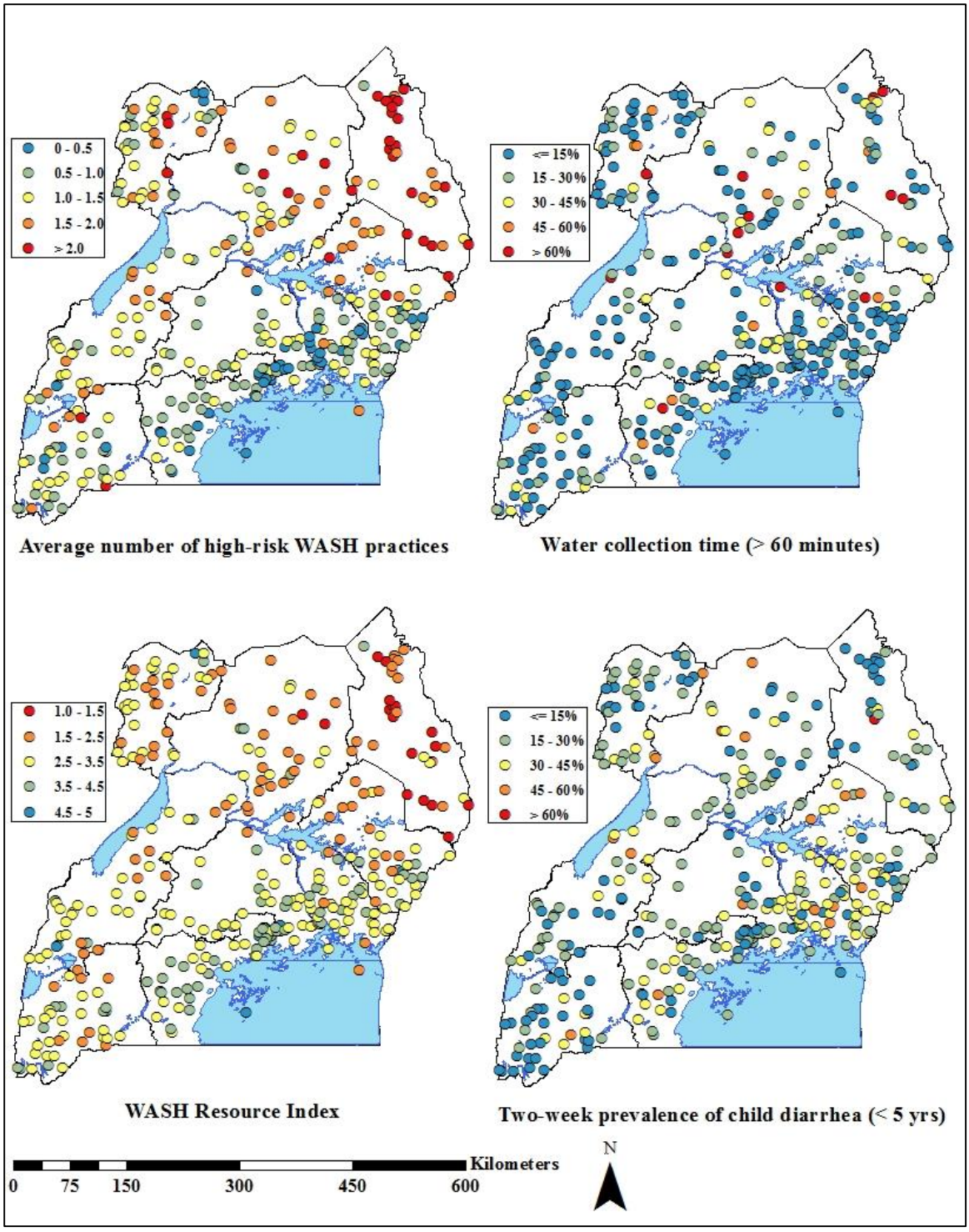

Figure 2. Geographical distributions of the average number of high-risk WASH practices, water collection over 60 minutes, WASH Resource quintiles, and two-week prevalence of child diarrhea at the cluster level in Uganda.

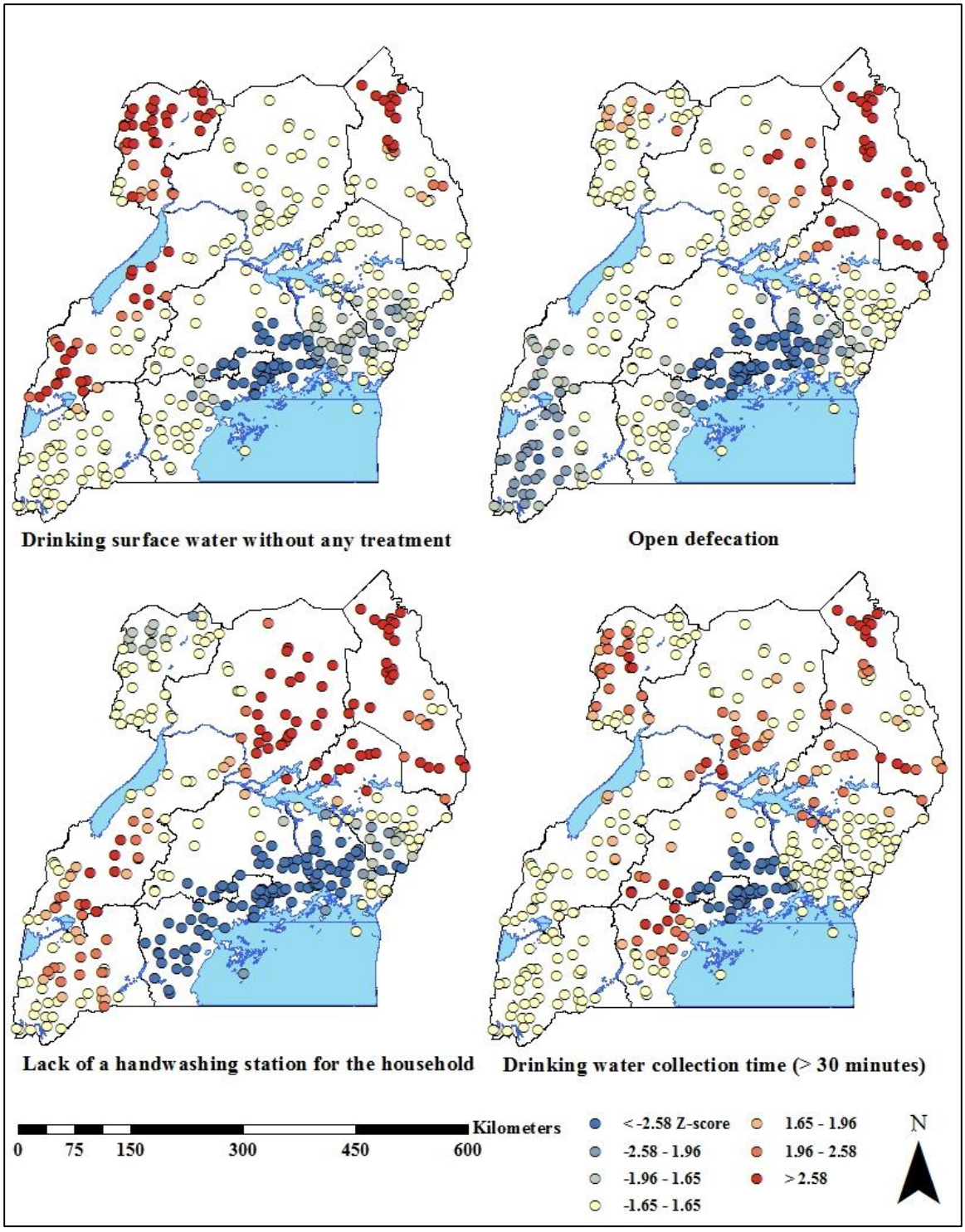

Figure 3. A hot spot analysis of high-risk WASH practices at the cluster level in Uganda.

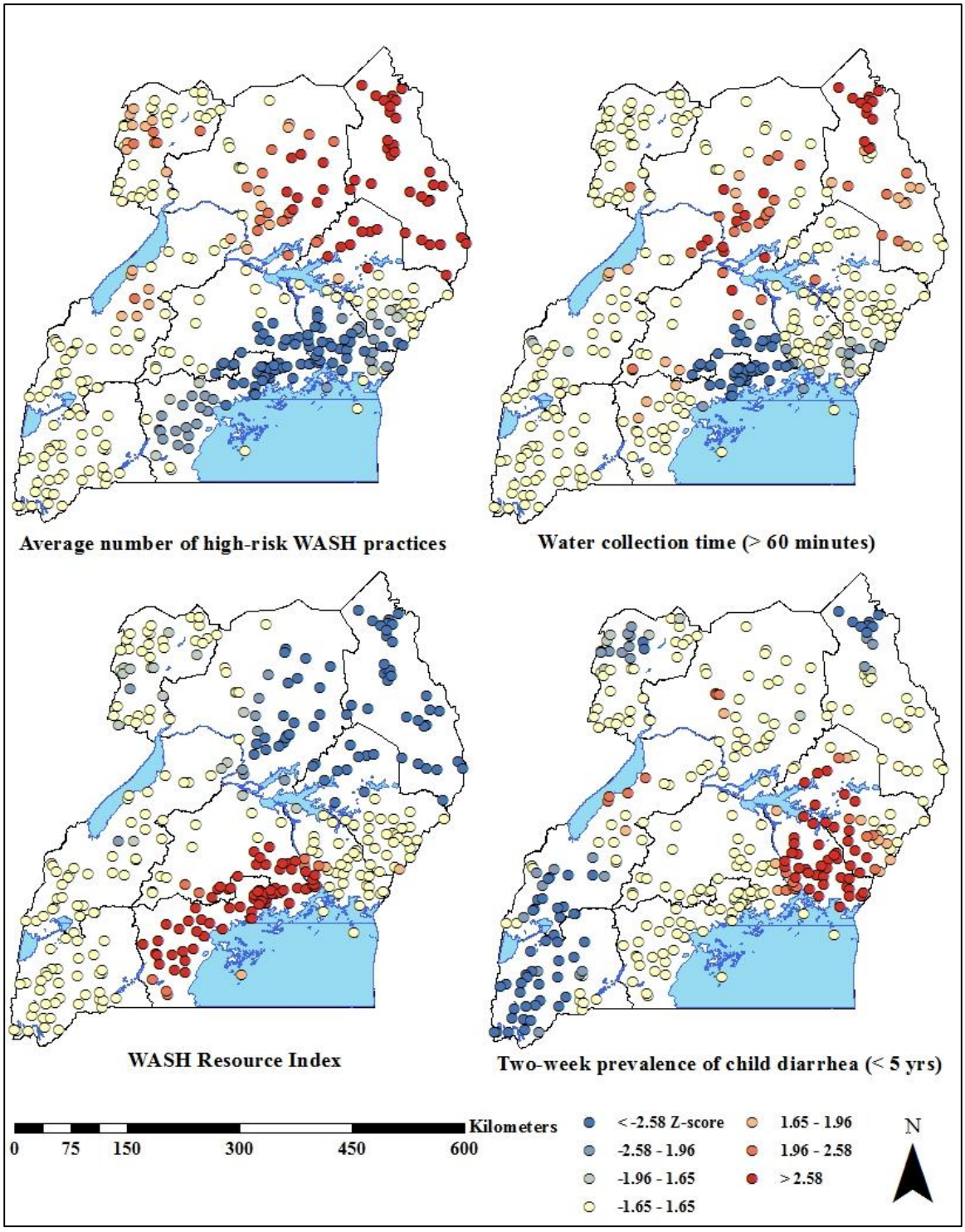

Figure 4. A hot spot analysis of the average number of high-risk WASH practices, water collection over 60 minutes, WASH Resource quintiles, and two-week prevalence of child diarrhea at the cluster level in Uganda.

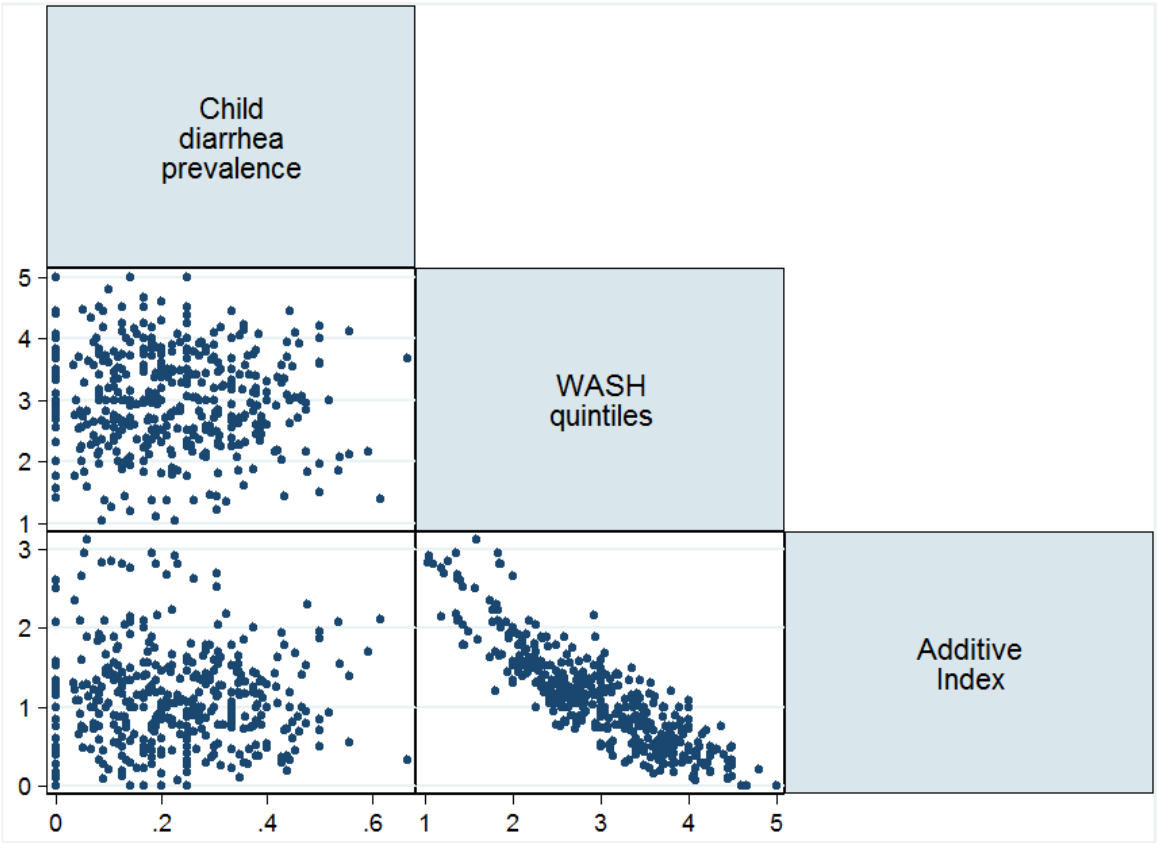

Figure 5. A scatter plot matrix of two-week prevalence of child diarrhea, the average number of high-risk WASH practices, and the average WRI quintiles at the cluster level.

Chapter 5: A Summary of the Findings and Conclusion

The detailed descriptions of results and discussions of this dissertation research can be found in three manuscripts. This chapter highlights some of the key findings and concludes with the overall implication of this research.

Study 1: Determinants of Handwashing with Soap in Indonesia

The first study examined the prevalence of handwashing with soap in six districts of Indonesia estimated by self-reporting, observed availability of water and soap at a handwashing place, an observed handwashing demonstration, and a composite measure of these three measurement methods. The estimated prevalence of handwashing with soap ranged from 55.7% by the composite measure to 75.2% by handwashing demonstrations. The prevalence was estimated to be much lower at specific handwashing moments, such as after defecation and before feeding children. Only 1.8% of all respondents were estimated to wash their hands with soap at all of the critical handwashing moments including after defecation, before eating, before feeding children, and after cleaning child stools.

The original hypothesis for multivariate analysis was rephrased to the following: motivations for handwashing, self-reported handwashing moments, and access to handwashing facilities are significantly associated with handwashing with soap, which may be collectively moderated by socio-demographic and structural factors. The results revealed that a desire for good smell, being told to wash hands, presence of handwashing places within 10 paces of the kitchen and the toilet, and a few handwashing moments,

such as before feeding, after eating, and after cleaning child stools, are significantly associated with handwashing with soap.

Study 2: Handwashing Ladder Development and Child Diarrhea in SSA

The second study developed a handwashing ladder and examined its association with the two-week prevalence of child diarrhea in 25 countries in SSA. At the country level, the availability of water and soap at a handwashing place was positively associated with child diarrhea in Burkina Faso and Ghana while a negative association was found in Chad and Mauritania. A significant association was not found in other countries. Thus, a hypothesis was not fully supported with evidence.

This study also modified the originally proposed analysis by adding a pooled analysis to examine the association between the proposed handwashing ladder and child diarrhea after controlling for country fixed effects. More specifically, this study tested the following hypothesis: the presence of water and soap at a handwashing place is negatively associated with child diarrhea after controlling for country fixed effects and potential confounders. A protective effect was observed for a pooled analysis by controlling for country fixed effects only, but a significant association was lost after including other potential confounders in the model. The hypothesis for a pooled analysis was therefore not supported in this study. Nonetheless, this study highlighted the importance of access to water and soap at a handwashing place as a physical cue to facilitate handwashing practices.

Study 3: High-Risk WASH Practice and Spatial Disparities in Uganda

The third study examined the geographical distribution of high-risk WASH practices at the cluster level in Uganda. The spatial analysis displayed that lack of a handwashing place for the household and water collection time of greater than 30 minutes were highly prevalent across the country. Thus, the originally proposed analysis was slightly modified to map water collection time of greater than 60 minutes as an additional high-risk WASH practice. A hot spot analysis suggested that hot spots of high-risk WASH practices and the two-week prevalence of child diarrhea do not overlap geographically.

This study also investigated how each high-risk WASH practice and the WRI are associated with child diarrhea at the household level. Bivariate analyses suggested that individual high-risk WASH practices were not associated with child diarrhea, but a multivariate analysis suggested some protective effect of being in higher WASH quintiles. Thus, the hypothesis was partially supported with evidence. Additional research remains essential to understand the association of the WRI with other WASH-related health outcomes, such as respiratory infections and soil-transmitted helminths.

Justifications for using prevalence ratios

Each study employed the generalized linear model (Poisson Family, log link) to estimate the prevalence ratio (PR) of handwashing with soap (Study 1) and child diarrhea (Study 2 & Study 3). Although the log-binomial model may produce a slightly less biased PR estimate than that of the Poisson model, previous studies suggested that the log-binomial method often includes issues of statistical convergence (Barros & Hirakata,

2003; Coutinho, Scazufca, & Menezes, 2008). Empirical evidence also suggested that Poisson regression and log-binomial regression produce comparable estimates of prevalence ratios (Barros & Hirakata, 2003). Based on this evidence base of statistical methods and ease of interpretations, this research consistently estimated the outcome of each study by using Poisson regression.

Limitations

This research included a number of notable limitations that might compromise the overall internal validity and the external validity of the findings. All of the three studies analyzed observational cross-sectional data. While the DHS has attained a high level of generalizability of findings for large sample size, sampling strategy, and high response rates, a causal inference needs to be carefully made because temporal precedence of independent variables to the outcome variable was not fully established. The same weakness can be applicable to the KAP survey in Indonesia. The two-week recall period of child diarrhea was also subject to recall and reporting bias (Arnold et al., 2013), and the definition of diarrhea was not uniform across DHS and MICS countries. Thus, the outcome data might not be of the optimal accuracy. Compared to experimental studies, observational studies are also limited in controlling for unobserved heterogeneities or residual confounding. The findings of this dissertation therefore need to be understood as associative evidence. The unique limitations of each study were also highlighted in respective chapters.

Future studies can further expand the evidence base of handwashing research by focusing on the dose-response relationship between handwashing and child health

outcomes. A review of empirical evidence from 1879 to 1986 suggests that more frequent handwashing at healthcare settings leads to reductions in the rates of infectious diseases (Larson, 1988). Yet, empirical evidence remains limited in low-income countries to suggest how many times people need to wash their hands with soap to observe health benefits among children. Establishing such a dose response relationship in different contexts can inform what message can be sent to promote handwashing with soap more effectively.

Conclusion

This dissertation research uniquely contributes to the advancement of the WASH sector. The first study provided insights into what factors may promote or determine people's handwashing behaviors in Indonesia. Emotional and sociocultural factors were highlighted as key drivers of handwashing with soap in this context. A composite measure of handwashing with soap was also developed to estimate handwashing behaviors more accurately. The second study constructed a handwashing ladder and examined its association with child diarrhea. This ladder can be used to monitor the progress of improving access to handwashing facilities. The third study developed the WASH Resource Index and demonstrated how the four high-risk WASH practices—drinking surface water without any water treatment at point of use, open defecation, lack of handwashing, and water collection taking 30 minutes or longer—were distributed in different geographical areas in Uganda. This study produced useful information for civil society organizations, donors, policy makers, and public health researchers to identify

most affected geographical areas from limited access to WASH and to implement targeted interventions.

This dissertation research focused on handwashing with soap as the main theme across the three studies to accelerate hygiene promotion efforts in low- and middle-income countries. Although global monitoring efforts on handwashing were limited under the MDG framework, the proposed indicators for the Sustainable Development Goals (SDGs) included "percentage of population using safely managed sanitation services, including a handwashing facility with soap and water" (United Nations, 2015, p. 22). Thus, the hygiene sector has gained momentum to monitor and promote handwashing with soap globally. Despite the current efforts to improve access to safe drinking water, adequate sanitation, and hand hygiene, numerous populations still engage in high-risk WASH practices and suffer from severe health consequences. WASH interventions with an additional emphasis on handwashing with soap remain essential to further reduce the global burden of disease and eliminate preventable child mortality in the world.

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