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Xinchun Yu Date

Association between water source and sanitation with anemia in preschool children: Biomarkers Reflecting Inflammation and Nutritional Determinants of Anemia (BRINDA) project

By

Xinchun Yu
Master of Public Health

Environmental Health

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Melissa F. Young, Ph.D., MPH
Committee Chair

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William Michael Caudle, Ph.D.
Committee Member

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Xinchun Yu
Bachelor of Medicine
Fudan University
2017

Thesis Committee Chair: Melissa F. Young, Ph.D., MPH
Thesis Committee Member: William Michael Caudle, Ph.D.

An abstract of

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Environmental Health
2019

ABSTRACT

Purpose: We aimed to assess the associations between water source and sanitation with anemia in preschool children (PSC; age: 6-59 months) using population-based surveys from the Biomarkers Reflecting Inflammation and Nutritional Determinants of Anemia (BRINDA) project.

Methods: We analyzed nationally and subnationally representative data from the BRINDA project. Fourteen surveys, representing 13 countries with PSC (N = 32,549) included measures of hemoglobin, household water source and sanitation, type of residence, and socioeconomic status (SES) and were included in analysis. Anemia was defined as hemoglobin concentration < 110 g/L, adjusting for altitude when this information was available. The household water source and sanitation were classified as either "improved" or "unimproved". Univariable analyses were done using Rao-Scott chi-square test. Multivariable analyses were done using logistic regressions.

Results: The percentage of participants with access to an improved household water source ranged from 44.2% in Laos to 96% in Bangladesh (2012) whereas the percentage of participants with access to improved household sanitation ranged from 0.2% in Kenya (2007) to 94.7% in Philippines. The country-level prevalence of anemia across these 14 surveys ranged from a low of 24.6% in Azerbaijan to a high of 71.7% in Kenya (2010). In the multivariable logistic regression models, access to improved sanitation source was associated with decreased odds of anemia in 5 out of 6 surveys assessed. However, none of these associations was significant at a significance level of 0.05.

Conclusions: Improved household water source and sanitation was not consistently associated with anemia across surveys. Further research is warranted to explore potential links between water source and sanitation with anemia from a clinical perspective.

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INTRODUCTION

Anemia remains a public health problem that affects both developing and developed countries and has substantial adverse health consequences (Balarajan, Ramakrishnan, Ozaltin, Shankar, & Subramanian, 2011), as well as economic impacts (Balarajan et al., 2011; Hernandez & Alcazar, 2013). Compared with other vulnerable groups, preschool children (PSC, aged 6-59.88 months) continued to have the highest prevalence of anemia (World Health Organization, 2015). In 2011, the prevalence of anemia was estimated to be 43% in children (Stevens et al., 2013). This prevalence translated to 273 million children with anemia worldwide in 2011 (Stevens et al., 2013). Furthermore, 1.5% of children were estimated to have severe anemia globally (Stevens et al., 2013).

Lack of safe water, sanitation, and hygiene (WASH) practices can lead to malnutrition via intestinal parasite infections, environmental enteropathy, and diarrheal diseases (WHO, UNCF,

& USAID, 2015). Inflammation arising from intestinal parasite infections, environmental enteropathy, and diarrheal diseases may also be an underlying cause of anemia (Ngure et al., 2014). Inflammation may induce anemia by reducing iron absorption by erythroblasts, diverting iron from the circulation into the storage sites of the reticuloendothelial system, and decreasing plasma retinol (Weiss & Goodnough, 2005).

The objective of this analysis was to assess the associations between water, sanitation and anemia in PSC in a variety of settings through a secondary analysis of a database of 29 population-based surveys that have been assembled under the Biomarkers Reflecting Inflammation and Nutritional Determinants of Anemia (BRINDA) project (Suchdev et al., 2016). We hypothesize that anemia is associated with poor hygienic conditions, which will induce poor gut health and chronic immune stimulation (Figure 1).

METHODS

Data sources

We used nationally and subnationally representative data from the BRINDA project (Suchdev et al., 2016). The BRINDA protocol was regarded as non-human subjects research by the Institutional Review Board (IRB) of the National Institutes of Health (NIH) (Namaste, Rohner, et al., 2017). The inclusion and exclusion criteria, laboratory analysis, and data management for the BRINDA project have been described in detail elsewhere (Suchdev et al., 2016). The inclusion criteria for this analysis were: the survey had measures of hemoglobin, household water source and sanitation, type of residence, and socioeconomic status (SES).

Case definitions

The primary outcome was anemia, which was defined as hemoglobin concentration < 110 g/L (World Health Organization, 2011). Severe anemia was defined as hemoglobin concentration <

70 g/L (World Health Organization, 2011). Hemoglobin concentrations were adjusted for altitude when this information was available. Inflammation was defined as AGP > 1 g/L or CRP > 5 mg/L.

For the WASH variables, there was a wide variation in types of water source or sanitation service. For the purpose of this study, water source and sanitation were defined as improved/unimproved household drinking water source and improved/unimproved toilet facility, respectively. For each variable (water source or sanitation), values of 1 and 0 were assigned to "improved" and "unimproved" service, respectively. Poor sanitation conditions comprised unimproved services and open defecation.

Statistical analysis

For descriptive statistics, we examined the characteristics of basic sociodemographic, overall water source and sanitation, and prevalence of anemia by survey. Associations between anemia and each potential covariate were tested separately for each survey using the Rao-Scott chi-square test (except for age and SES, which were separately examined with the use of a univariable survey logistic regression procedure). Prevalence ratios were estimated for each survey. We chose potential confounders based on a conceptual framework outlining the expected relations between anemia and selected potential risk factors for anemia (Namaste, Aaron, et al., 2017), as well as data availability.

Multivariable logistic regression models were conducted to examine associations between anemia with water source and/or sanitation. The model construction procedures were as follows. (1) Any covariate whose univariable test has a p-value less than 0.05 was selected into the multivariable logistic regression models; (2) interaction between water source and sanitation was assessed by examining the parameter estimates associated with the product term; (3) a change-in-estimate method, i.e., the 10% rule, was used to select influential confounders into the final logistic regression models. All the analyses were conducted with SAS version 9.4 version software (SAS Institute), taking into account for the sampling weight, cluster, and stratum. Sampling weights, clusters, and strata were provided by survey representatives.

RESULTS

Descriptive statistics

Our final sample included 32,549 PSC in 14 surveys, representing 13 countries (Figure 2). The median of age differed from 15.3 months in Philippines to 38 months in Bangladesh (2012) (Table 1). There was also a wide distribution of type of residence and SES across the 14 surveys (Table 1). Twenty-nine percent of the participants in Colombia were from rural areas while all the participants in the 2 Kenya surveys were from rural areas (Table 1).

The percentage of participants with access to an improved household water source ranged from 44.2% (95% CI: 32.8%-55.6%) in Laos to 96% (95% CI: 91.3%-100%) in Bangladesh (2012) whereas the percentage of participants with access to improved household sanitation ranged from 0.2% (95% CI: 0%-0.5%) in Kenya (2007) to 94.7% (95% CI: 95.7%-99.1%) in Philippines (Table 2).

The country-level prevalence of anemia across these 14 surveys ranged from a low of 24.6% (95% CI: 21.2%-28%) in Azerbaijan to a high of 71.7% (95% CI: 68.1%-75.2%) in Kenya (2010) (Table 2). The highest prevalence of severe anemia was 5.1% (95% CI: 4.5%-5.7%) (Table 2). In all the other surveys, the prevalence of severe anemia was < 5% and thus, we focused on anemia only for further analyses (Table 2).

Univariable associations

Access to unimproved sanitation source was significantly associated with increased prevalence of anemia in 6 out of 12 surveys examined, specifically Cameroon (PR: 1.2, 95% CI: 1.1-1.4), Ecuador (PR: 1.6, 95% CI: 1.1-2.3), Azerbaijan (PR: 1.4, 95% CI: 1-2), Cambodia (PR: 1.2, 95% CI: 1-1.4), Philippines (PR: 1.6, 95% CI: 1.2-2.1), and Papua New Guinea (PR: 1.3, 95% CI: 1-1.7) (Table 3; Figure 3). Relationships were non-significant in the remaining 6 surveys (Table 3).

Access to unimproved water source was significantly associated with increased prevalence of anemia in Cameroon (PR: 1.2, 95% CI: 1-1.4), Azerbaijan (PR: 1.3, 95% CI: 1-1.7), and Laos (PR: 1.4, 95% CI: 1-1.9) (Table 3; Figure 3). A reverse relationship was observed in Philippines (PR: 0.7, 95% CI: 0.6-0.9) (Table 3; Figure 3). Relationships were non-significant in the remaining 9 surveys (Table 3).

Multivariable logistic regression models

In the multivariable logistic regression models, access to improved sanitation source was associated with decreased odds of anemia in 5 out of 6 surveys assessed, specifically Cameroon (aOR = 0.84), Ecuador (aOR = 0.63), Azerbaijan (aOR = 0.71), Philippines (aOR = 0.46), and Papua New Guinea (aOR = 0.64) (Table 4; Figure 4). However, none of these associations were significant at a traditional significance level of 0.05 (Table 4; Figure 4). An inverse association was observed in Cambodia (aOR = 1.24, 95% CI: 0.74-2.09), but this association was not significant too (Table 4; Figure 4).

Among the 4 surveys assessed in multivariable logistic regression models, access to improved water source was associated with an unexpected increased odds of anemia in Philippines (OR =

1.51, 95% CI: 1.09-2.08) (Table 3). Relationships were non-significant in the remaining 3 surveys assessed (Table 3).

DISCUSSION

To the best of our knowledge, this analysis is one of the first to directly explore the associations between household water and sanitation practices and anemia in PSC across multiple countries using national and subnational surveys. A main strength of this analysis is the large sample size and the availability of household-level data on types of drinking water source and sanitation. We relied on data from a large number of surveys that included a wide range of geographical regions and covered a broad range of PSC. This analysis also advanced existing BRINDA work by addressing the “unhealthy environment” component in the BRINDA project’s anemia conceptual framework (Namaste, Aaron, et al., 2017).

One of our most interesting findings is that the percentages of participants with access to improved household water source/sanitation vary greatly across geographical regions, so is the prevalence of anemia. Another interesting finding is that 6 out of 12 surveys show a significant positive association between unimproved sanitation and anemia, indicating improved sanitation may be protective of anemia. However, after adjusting for confounding, these associations are no longer significant.

These results suggest that sanitation at the household level itself may not be enough to have a protective effect. According to a previous study, a lack of sanitation access at the community level was a significant risk factor for anemia independent of household-level sanitation access (Larsen, Grisham, Slawsky, & Narine, 2017). The mechanism behind this was that community-level sanitation might act through a type of “herd-immunity” mechanism (Fuller & Eisenberg, 2016).

There are several caveats to this study. First, due to the cross-sectional nature of the BRINDA database, we are unable to make any causal inference. Second, hygiene variable, an important component of WASH practices, is not available in the database. Third, due to zero-cell issue, we simplified sanitation access as having either improved or unimproved sanitation facility, while in reality the sanitation ladder is much more nuanced (Kvarnström, McConville, Bracken, Johansson, & Fogde, 2011). Fourth, there is great heterogeneity in data quality and measurements method across countries. Finally, information on other potential confounders of the association between water, sanitation practices and anemia, such as genetic factors, is not available.

In this analysis, we used a purposeful selection approach to build our final multivariable regression models (Hosmer Jr, Lemeshow, & Sturdivant, 2013). There is another approach suggesting including all clinically and intuitively relevant variables in the final multivariable regression models, regardless of their statistically significance (Hosmer Jr et al., 2013). And this is our next step to explore the clinical associations between water source and sanitation with anemia.

In conclusion, improved household water source and sanitation was not consistently associated with anemia across surveys. Further research is warranted to explore potential links between water source and sanitation with anemia from a clinical perspective.

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Competing interests

None of the authors reported a conflict of interested related to the study.

Ethical approval

This study used secondary data, so did not require ethical approval.

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Table 1. Sociodemographic characteristics in preschool children by survey: the BRINDA project[1]

WHO region/Country (Year)	N	Male, % (95% CI)	Age,[2] median (min-max)	Rural, % (95% CI)	Lower SES[3], % (95% CI)
Africa					
Cameroon (2009)	815	50.2 (46.9, 53.5)	29.8 (12-59.9)	41.1 (31.3, 51)	44.4 (37.1, 51.7)
Kenya (2007)	1056	51.6 (48.9, 54.3)	19.3 (6-36)	100	41.2 (36.1, 46.3)
Kenya (2010)	896	50.1 (46.7, 53.4)	22.3 (6-35)	100	39.7 (34.4, 45)
Liberia (2011)	1476	50.7 (47.9, 53.5)	18.9 (6-35.9)	63.8 (60.4, 67.1)	36.8 (30.7, 43)
Malawi (2016)	1233	50 (47.3, 52.6)	31.1 (6-59)	90.2 (80.5, 100)	50.2 (44.2, 56.2)
Americas					
Colombia (2010)	7753	52.4 (50.9, 53.9)	27.6 (6-59)	29.2 (28, 30.4)	50.7 (49, 52.3)
Ecuador (2012)	2020	56.8 (52.5, 61.1)	27.3 (6-59)	33.9 (22.1, 45.7)	50.9 (45.7, 56.1)
Asia					
Bangladesh (2012)	1108	50.3 (44.6, 56.1)	38 (6-59)	75.2 (68, 82.4)	50 (42.5, 57.4)
Pakistan (2011)	10689	52.1 (51, 53.3)	24.5 (6-59)	70.3 (67.7, 72.9)	43.2 (40.9, 45.4)
Europe					
Azerbaijan (2013)	1397	54.3 (51, 57.6)	32 (6-59)	52.6 (44.1, 61.1)	25.8 (21.3, 30.3)
Western Pacific					
Cambodia (2014)	874	53.6 (50.7, 56.6)	33.3 (6.1-60)	86.8 (81.1, 92.5)	40 (32.3, 47.7)
Laos (2006)	514	49.8 (45.6, 54)	32.9 (6-59)	84.5 (75.5, 93.6)	59.4 (48.8, 70)
Philippines (2011)	1784	49.9 (47, 52.9)	15.3 (6-24)	90.9 (90.2, 91.5)	84.5 (81.3, 87.6)
Papua New Guinea (2005)	934	54.7 (51.6, 57.9)	30 (6-59.8)	80.3 (71, 89.6)	40.2 (29, 51.3)

[1] BRINDA, Biomarkers Reflecting Inflammation and Nutritional Determinants of Anemia; SES, socioeconomic status.

[2] In months.

[3] SES was a 3-level ordinal variable created from asset quintiles or country income variables. Specifically, the 1st and 2nd quintiles/categories were collapsed as "low SES", the 3rd and 4th quintiles/categories were collapsed as "medium SES", and the 5th quintile/category was converted as "high SES".

Table 2. Prevalence of improved water source, sanitation, anemia, severe anemia, and inflammation in preschool children by survey: the BRINDA project[1]

WHO region/Country (Year)	Improved water source, % (95% CI)	Improved sanitation, % (95% CI)	Inflammation, % (95% CI)	Anemia, % (95% CI)	Severe anemia, % (95% CI)
Africa					
Cameroon (2009)	72.3 (66.8, 77.8)	62.7 (56.9, 68.4)	48.1 (42.9, 53.3)	54.1 (49.2, 59)	3.1 (1.7, 4.4)
Kenya (2007)	51.2 (41.2, 61.2)	0.2 (0, 0.5)	66 (61.9, 70.1)	65.7 (62, 69.4)	2.8 (1.8, 3.9)
Kenya (2010)	53.5 (44.1, 63)	1.1 (0.2, 2)	62 (57.3, 66.6)	71.7 (68.1, 75.2)	8 (6, 9.9)
Liberia (2011)	83.5 (76.7, 90.3)	52.3 (44.5, 60.2)	59.1 (55.6, 62.7)	59.3 (55.4, 63.1)	0.9 (0.3, 1.5)
Malawi (2016)	82.7 (75.8, 89.7)	82.6 (78.1, 87.1)	57 (51.5, 62.6)	31.6 (28, 35.3)	0.6 (0, 1.3)
Americas					
Colombia (2010)	87.8 (85.8, 89.9)	96.3 (95, 97.6)	18.8 (17.1, 20.5)	26.8 (25.5, 28.2)	0.1 (0, 0.3)
Ecuador (2012)	77.8 (73.2, 82.3)	93.7 (92.2, 95.2)	12.5 (10.1, 14.9)	24.7 (20.9, 28.5)	0 (0, 0.1)
Asia					
Bangladesh (2012)	96 (91.3, 100)	70 (61.4, 78.6)	28.9 (23, 34.8)	33.1 (25.7, 40.5)	0 (0, 0)
Pakistan (2011)	94.5 (93.5, 95.5)	94.7 (94, 95.5)	35.5 (34, 36.9)	63 (61.7, 64.2)	5.1 (4.5, 5.7)
Europe					
Azerbaijan (2013)	80.2 (73.1, 87.4)	94.1 (91.6, 96.7)	30.9 (27.1, 34.6)	24.6 (21.2, 28)	0.5 (0, 1.4)
Western Pacific					
Cambodia (2014)	54.7 (46.4, 62.9)	53.9 (46.5, 61.2)	38.3 (30.6, 46)	55.7 (50.6, 60.7)	0.7 (0, 1.4)
Laos (2006)	44.2 (32.8, 55.6)	88 (79.3, 96.7)	43.9 (36.5, 51.4)	40.7 (31.5, 49.9)	0.5 (0, 1.1)
Philippines (2011)	44.8 (40.4, 49.2)	97.4 (95.7, 99.1)	26 (22.4, 29.5)	41.8 (37.8, 45.9)	0.3 (0, 0.7)
Papua New Guinea (2005)	66.4 (57, 75.7)	10 (3.7, 16.3)	57 (52.6, 61.5)	47.9 (42.5, 53.4)	2.5 (1.2, 3.9)

[1] Inflammation was defined as having AGP > 1 g/L or CRP > 5 mg/L. Anemia was defined as having hemoglobin concentration < 110 g/L. Severe anemia was defined as having hemoglobin concentration < 70 g/L. BRINDA, Biomarkers Reflecting Inflammation and Nutritional Determinants of Anemia.

Table 3. Univariable associations between anemia and covariates in preschool children by survey: the BRINDA project[1]

WHO region/Country (Year)	Sex, M	Older age[2], β (SE)	Urban	Higher SES[3], β (SE)	Unimproved water source	Unimproved sanitation	No inflammation
Africa							
Cameroon (2009)	1.1 (1, 1.3)*	-0.03 (0.01)**	0.8 (0.7, 1)	-0.71 (0.14)**	1.2 (1, 1.4)*	1.2 (1.1, 1.4)**	0.6 (0.5, 0.7)**
Kenya (2007)	1.1 (1, 1.2)	-0.02 (0.01)*	Non-est	0.04 (0.08)	0.9 (0.9, 1)	Non-est	0.8 (0.7, 0.9)**
Kenya (2010)	1.1 (1, 1.2)*	-0.03 (0.01)*	Non-est	-0.26 (0.11)*	1.1 (1, 1.2)	Non-est	0.7 (0.6, 0.7)**
Liberia (2011)	1.1 (1, 1.2)*	-0.01 (0.01)	0.9 (0.8, 1)	-0.08 (0.09)	0.9 (0.7, 1)	1 (0.9, 1.1)	0.8 (0.7, 0.9)**
Malawi (2016)	1.2 (0.9, 1.5)	-0.04 (0.01)**	1.1 (0.9, 1.4)	-0.11 (0.17)	1.1 (0.8, 1.4)	0.9 (0.6, 1.3)	0.6 (0.4, 0.9)**
Americas							
Colombia (2010)	1.1 (1, 1.2)	-0.06 (0.003)**	0.8 (0.8, 0.9)**	-0.32 (0.06)**	1 (0.8, 1.4)	1.2 (0.7, 2.2)	0.8 (0.7, 1.1)
Ecuador (2012)	1 (0.8, 1.3)	-0.09 (0.01)**	1.2 (0.9, 1.6)	-0.61 (0.13)**	1.1 (0.9, 1.4)	1.6 (1.1, 2.3)*	0.7 (0.5, 1)
Asia							
Bangladesh (2012)	1.1 (0.7, 1.6)	-0.02 (0.01)	0.6 (0.4, 1)*	0.13 (0.26)	Non-est	1.3 (0.8, 1.9)	0.6 (0.4, 1.1)
Pakistan (2011)	1 (1, 1)	-0.02 (0.002)**	1 (1, 1.1)	-0.19 (0.03)**	1 (1, 1.1)	1.1 (1, 1.2)	0.9 (0.8, 0.9)**
Europe							
Azerbaijan (2013)	1.4 (1.1, 1.8)**	-0.02 (0.01)**	0.8 (0.6, 1)	-0.19 (0.13)	1.3 (1, 1.7)*	1.4 (1, 2)*	0.6 (0.5, 0.8)**
Western Pacific							
Cambodia (2014)	0.9 (0.7, 1)*	-0.04 (0.01)**	0.8 (0.6, 0.9)*	-0.47 (0.13)**	1 (0.8, 1.2)	1.2 (1, 1.4)*	0.9 (0.8, 1.1)
Laos (2006)	1.2 (0.9, 1.6)	-0.04 (0.01)**	0.6 (0.3, 1.1)*	-0.17 (0.23)	1.4 (1, 1.9)*	1.7 (1, 3)	0.9 (0.7, 1.2)
Philippines (2011)	1 (0.8, 1.1)	-0.07 (0.02)**	1 (0.9, 1.2)	-0.53 (0.2)**	0.7 (0.6, 0.9)**	1.6 (1.2, 2.1)*	0.8 (0.7, 0.9)**
Papua New Guinea (2005)	1 (0.9, 1.1)	-0.03 (0.01)**	0.8 (0.6, 1.2)	0.04 (0.15)	1.2 (0.9, 1.6)	1.3 (1, 1.7)*	0.7 (0.6, 0.8)**

[1] All value are prevalence ratios (95% CI). Anemia was defined as having hemoglobin concentration < 110 g/L. Unimproved sanitation included unimproved sanitation and open defecation. Inflammation was defined as having AGP > 1 g/L or CRP > 5 mg/L. P-values are from Rao-Scott chi-square test except for age and SES which were used respectively to fit a univariable logistic regression model: $*P < 0.05$, $**P < 0.01$. BRINDA, Biomarkers Reflecting Inflammation and Nutritional Determinants of Anemia; SES, socioeconomic status; Non-est, non-estimable due to zero-cell issue.

[2] In months.

[3] SES was a 3-level ordinal variable created from asset quintiles or country income variables. Specifically, the 1st and 2nd quintiles/categories were collapsed as "low SES", the 3rd and 4th quintiles/categories were collapsed as "medium SES", and the 5th quintile/category was converted as "high SES".

Table 4. Multivariable logistic regression model of the associations between anemia, water, and/or sanitation by survey in preschool children by survey: the BRINDA project[1]

WHO region/Country (Year)	Covariates in the final model	Improved water	Improved sanitation
Africa			
Cameroon (2009)	sex, age, SES, water, sanitation, inflammation	0.95 (0.61, 1.49)	0.84 (0.62, 1.13)
Kenya (2007)	N/A	N/A	N/A
Kenya (2010)	N/A	N/A	N/A
Liberia (2011)	N/A	N/A	N/A
Malawi (2016)	N/A	N/A	N/A
Americas			
Colombia (2010)	N/A	N/A	N/A
Ecuador (2012)	age, SES, sanitation	N/A	0.63 (0.36, 1.13)
Asia			
Bangladesh (2012)	N/A	N/A	N/A
Pakistan (2011)	N/A	N/A	N/A
Europe			
Azerbaijan (2013)	sex, age, water, sanitation, inflammation	0.72 (0.48, 1.09)	0.71 (0.42, 1.2)
Western Pacific			
Cambodia (2014)	sex, age, rural, SES, sanitation	N/A	1.24 (0.74, 2.09)
Laos (2006)	age, rural, water, sanitation	0.88 (0.42, 1.83)	N/A
Philippines (2011)	age, SES, water, sanitation, inflammation	1.51 (1.09, 2.08)	0.46 (0.2, 1.06)
Papua New Guinea (2005)	sanitation	N/A	0.64 (0.4, 1.03)

[1] All value are odds ratios (95% CI). Anemia was defined as having hemoglobin concentration < 110 g/L. Inflammation was defined as having AGP > 1 g/L or CRP > 5 mg/L. N/A, not assessed because neither water nor sanitation was significant in the univariable analysis. BRINDA, Biomarkers Reflecting Inflammation and Nutritional Determinants of Anemia; SES, socioeconomic status;

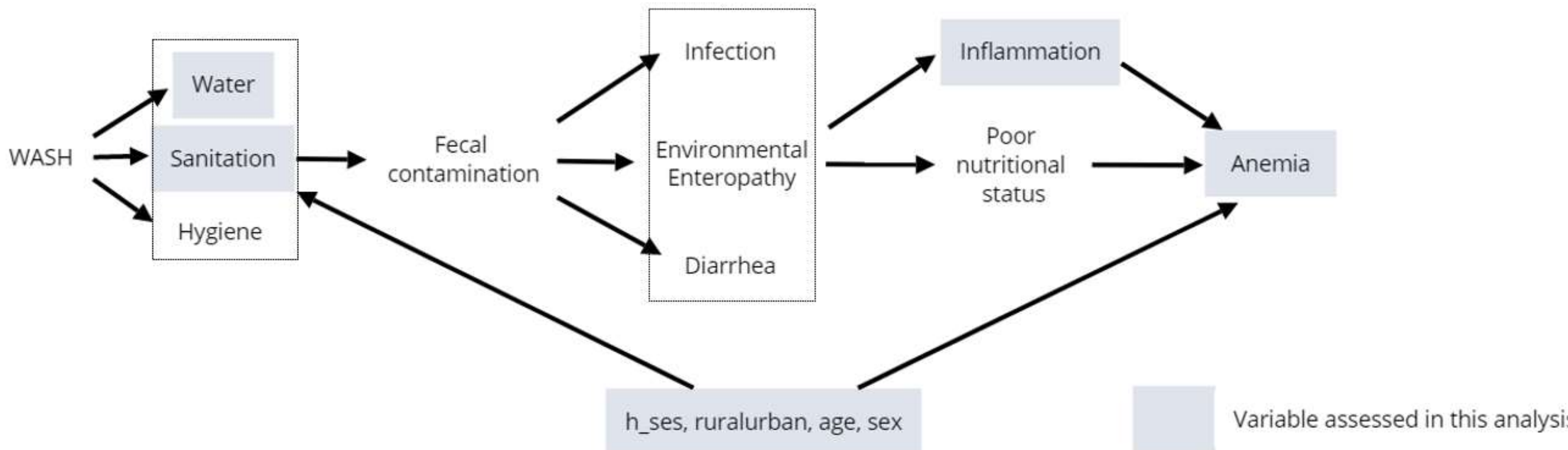

Figure 1. Conceptual framework showing variables included in this analysis. Water was defined as improved or unimproved household main drinking water source. Sanitation was defined as improved or unimproved household sanitation, and unimproved sanitation included unimproved sanitation and open defecation. Inflammation was defined as having AGP > 1 g/L or CRP > 5 mg/L. Anemia was defined as having hemoglobin concentration < 110 g/L. SES was a 3-level ordinal variable created from asset quintiles or country income variables. Specifically, the 1st and 2nd quintiles/categories were collapsed as "low SES", the 3rd and 4th quintiles/categories were collapsed as "medium SES", and the 5th quintile/category was converted as "high SES". SES, socioeconomic status.

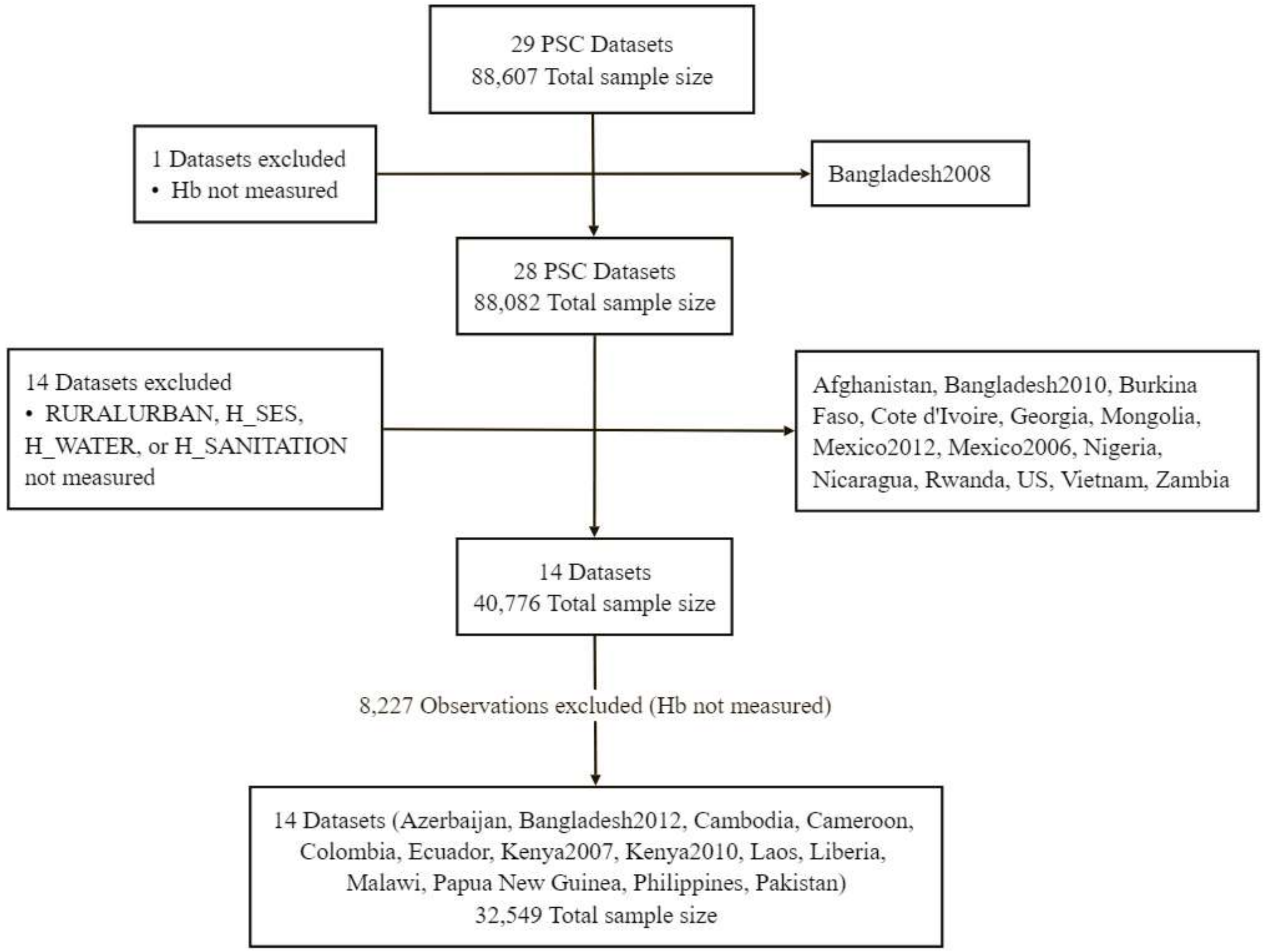

Figure 2. Sample size for this analysis. PSC, preschool children; Hb, hemoglobin; RURALURBAN, type of residence (rural or urban); H_SES, household socioeconomic status; H_WATER, household main drinking water source (improved or unimproved); H_SANITATION, household sanitation(improved or unimproved).

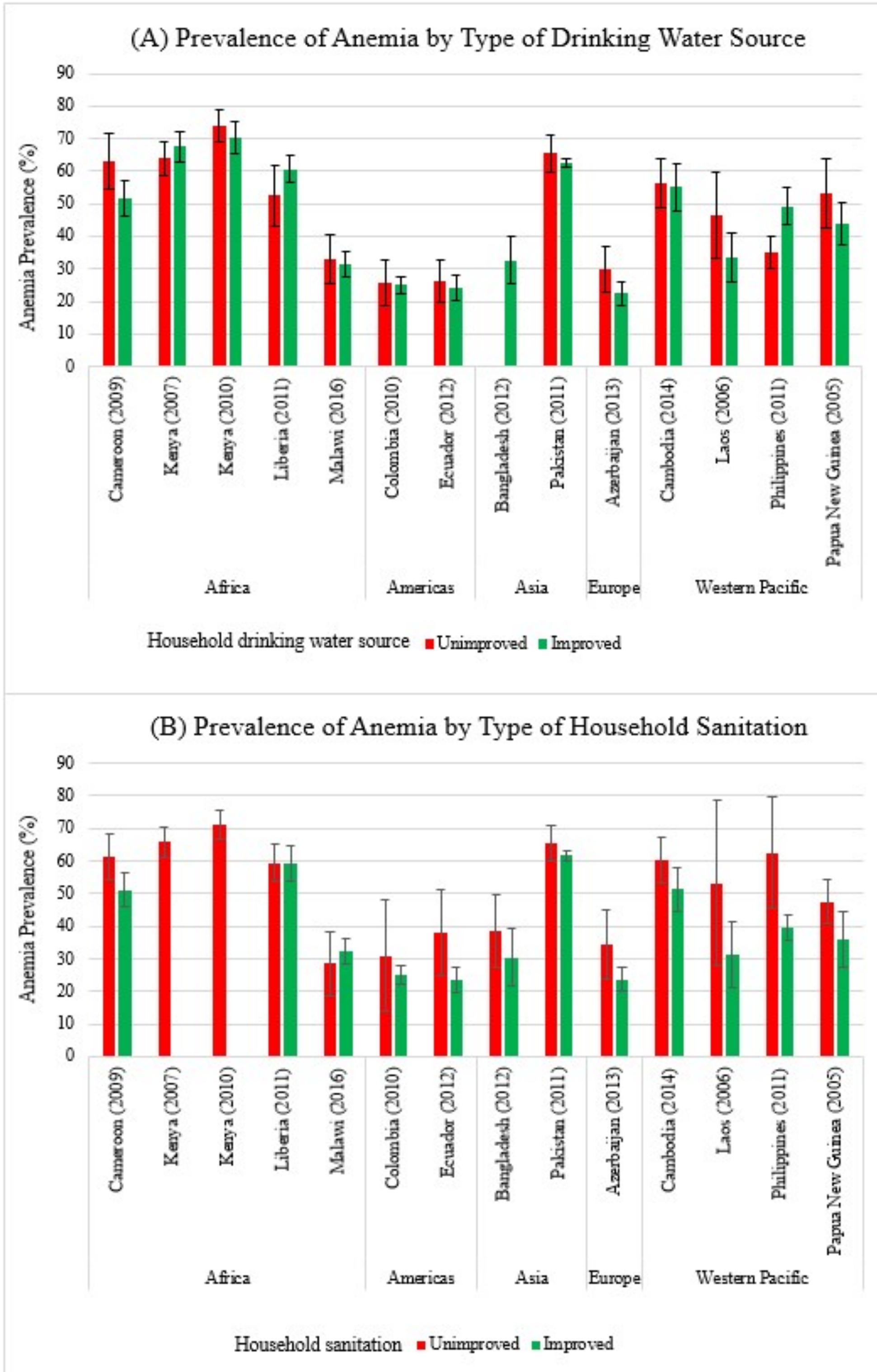

Figure 3. Prevalence of anemia by (A) type of household water source or (B) type of household sanitation by survey. Anemia was defined as having hemoglobin concentration < 110 g/L.

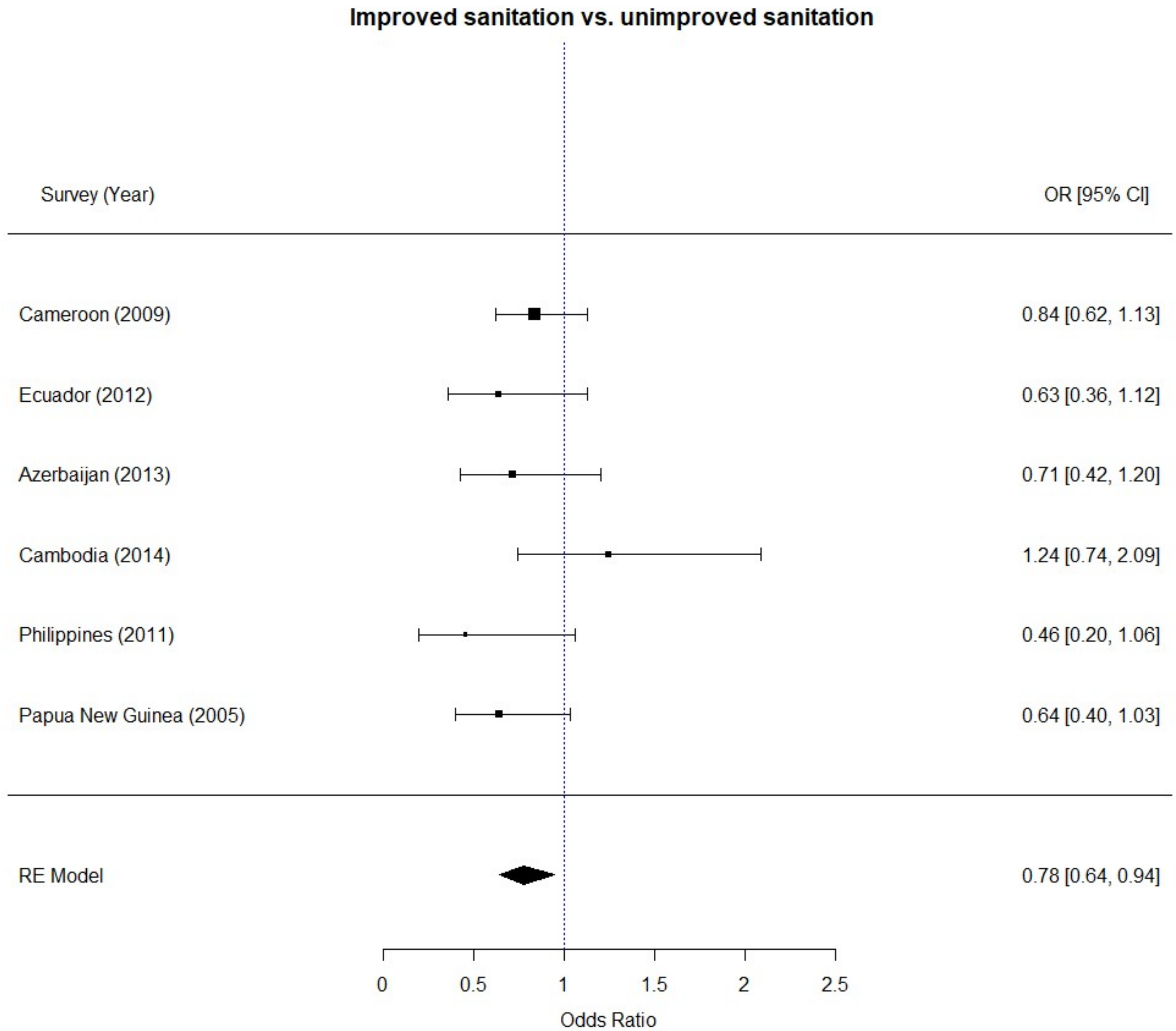

Figure 4. Forest plot for the adjusted odds ratio. Anemia was defined as having hemoglobin concentration < 110 g/L. Water was defined as improved or unimproved household main drinking water source. Sanitation was defined as improved or unimproved household sanitation, and unimproved sanitation included unimproved sanitation and open defecation. Inflammation was defined as having AGP > 1 g/L or CRP > 5 mg/L. SES was a 3-level ordinal variable created from asset quintiles or country income variables. Specifically, the 1st and 2nd quintiles/categories were collapsed as "low SES", the 3rd and 4th quintiles/categories were collapsed as "medium SES", and the 5th quintile/category was converted as "high SES". Covariates in final models: Cameroon: sex, age, SES, water, sanitation, inflammation; Ecuador: age, SES, sanitation; Azerbaijan: sex, age, water, sanitation, inflammation; Cambodia: sex, age, rural, SES, sanitation; Laos: age, rural, water, sanitation; Philippines: age, SES, water, sanitation, inflammation; Papua New Guinea: sanitation. SES, socioeconomic status.