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Livestock Ownership among Rural Households and Child Morbidity and Mortality: An Analysis of Demographic Health Survey Data from 30 Sub-Saharan African Countries (2005–2015)

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Abstract.

Children living in homes with livestock may have both an increased risk of enteric infections and improved access to food, and therefore improved nutritional status. Few studies, however, have characterized these relationships in tandem. This study investigated the association between child health and household ownership of livestock. A cross-sectional study was performed using data from Demographic and Health Surveys conducted in 30 sub-Saharan African countries with 215,996 rural children under 5 years of age from 2005 to 2015. Logistic regression was performed for each country to estimate the relationship between a $\log_2$ increase in the number of livestock owned by the household and three child-health outcomes: 2-week prevalence of diarrhea, stunting, and all-cause mortality. Results for each country were combined using meta-analyses. Most countries (22 of 30) displayed an odds ratio (OR) less than 1 for child stunting associated with livestock (pooled OR = 0.97; 95% confidence interval [CI] = 0.95, 0.99). The results for diarrhea were more even with 13 countries displaying ORs greater than 1 and seven displaying ORs less than 1. Most countries (22 of 30) displayed an OR greater than 1 for child mortality (pooled OR = 1.04; 95% CI = 1.02, 1.06). All meta-analyses displayed significant heterogeneity by country. Our analysis is consistent with the theory that livestock may have a dual role as protective against stunting, an indicator of chronic malnutrition, and a risk factor for all-cause mortality in children, which may be linked to acute infections. The heterogeneity by country, however, indicates more data are needed on specific household livestock management practices.

INTRODUCTION

Undernutrition is estimated to be an underlying cause for 3.1 million annual deaths in children under 5 years of age, occurring mainly in low- and middle-income countries (LMICs).[1] Undernutrition has also been shown to detrimentally affect children's physical and cognitive development and make them more susceptible to infectious diseases, such as diarrhea.[2] Diarrheal disease is a contributor to chronic ailments associated with undernutrition. Enteric infections may also lead to a subclinical condition of the gut called environmental enteric dysfunction, resulting in impaired nutrient absorption and altered immune function that can compromise growth and cognitive development in children over time.[3] Diarrheal disease also contributes to acute disease burden and is the second leading cause of mortality in children under 5 years of age globally.[2,4]

A substantial amount of attention has been focused on poor water, sanitation, and hygiene practices (WASH), which are recognized risk factors for the majority of diarrheal deaths in LMICs.[5] WASH interventions are generally focused on breaking the human fecal–oral route of disease. One underrecognized source of fecal contamination, however, is animal feces, which are common contaminants in the environment of children living in poor communities of LMICs.[6] Exposures to animal feces will likely increase as small-scale animal agriculture—promoted for rural development—expands.[7] A systematic review of human diarrhea infections and livestock ownership suggested evidence for animals as risk factors for diarrhea, especially when specific animal and pathogen combinations were studied.[8] The greatest risk observed in the review was for poultry. *Campylobacter*, associated with chicken feces, was the main enteric pathogen observed in infected children.[8–13] There remains, however, an important gap in our ability to estimate the risk of specific animal species, animal holding practices, and zoonotic pathogenic species contributing to the transmission of zoonotic enteric infections to children.[14] Understanding the role that small-scale livestock production plays in contributing to diarrhea and other zoonotic infectious diseases is critical.

In addition to zoonotic infectious diseases, such as diarrhea, there is increasing evidence that fecal contamination associated with human and animal feces may be an important risk factor for environmental enteric dysfunction, a subclinical condition of the gastrointestinal tract that can detrimentally affect child nutrition and growth.[15] Researchers have found geophagy to be a common behavior among young children and soil has often been found to be contaminated with animal feces.[16] Researchers in India identified high levels of animal fecal markers in households and community water sources.[17] Research has also linked geophagy and chicken ownership to environmental enteric dysfunction and child stunting.[3,18]

Despite concerns about zoonotic exposures, livestock plays an essential role as sources of income and nutrition for households. Consumption of animal source foods, including eggs, milk, milk products, meat, poultry, and fish, have been shown to be protective against stunting and undernutrition.[19–21] In a study of 1,500 infants and 1,658 toddlers, most of whom were breastfed, researchers found that consumption of meat was associated with a reduced likelihood of stunting (odds ratio [OR] = 0.64; 95% confidence interval [CI] = 0.46–0.90).[22] A cross-sectional study of 183 Kenyan children under the age of 5, showed a positive association between female-owned livestock with children's weight-for-age *z* scores.[23] Further, in a review of interventions promoting animal production, researchers identified 14 studies that assessed the impacts of livestock ownership on dietary intake and household income—all studies showed a positive effect. Four of the 14 studies included nutritional status as an outcome measure and all identified positive effects.[24]

In this study, we used publicly available data to explore small-scale livestock ownership as both a risk factor and a protective factor for two acute child health outcomes, 2-week prevalence of diarrhea and all-cause child mortality, and a chronic outcome, stunting. We focus on children under 5 years of age in sub-Saharan Africa.

MATERIALS AND METHODS

Data.

Data for the analysis came from Demographic and Health Surveys (DHS) conducted in countries across sub-Saharan Africa between 2005 and 2015. We chose to focus on sub-Saharan

Africa, due to the high burden of morbidity and mortality in children.[25] The DHS are large nationally representative cross-sectional surveys that use the national census bureau to first stratify the country by geographic regions and then by urban/rural. From each stratum, DHS draws clusters from a census and randomly samples households from that cluster. The DHS survey is thus designed to produce representative estimates of the entire country, for urban/rural areas separately and for the geographical regions.[26] The target population for the survey is women age 15–49 and children under 5 years of age. Livestock ownership was much less prevalent among urban households and we expected a different dynamic between livestock and child health, so only children in rural households were included in the study.

Variables.

Anthropometric measurements on children were restricted to children born 5 years or less before the survey and alive at the time of the survey. Stunting was defined as having a height-for-age *z* score (HAZ) below or equal to −2 standard deviations (SDs), as measured against the World Health Organization's (WHO) international growth standards.[27,28] We used stunting as an indicator of long-term health impacts on child health.[29,30] For the diarrhea analyses, mothers were asked about the occurrence of diarrhea in the past 2 weeks. For the analysis of all-cause child mortality, we included all children born to mothers in the previous 5 years.

When comparing children with and without anthropometry data as well as children that were living and not living, we found that children without anthropometry data and children that were not living were significantly different from their counterparts across many of the countries with regard to age, maternal education, number of children in the household, and household wealth. Children without anthropometry data and children that were not living were on average younger, had mothers with less education, had fewer children in the household, and were less wealthy. To account for potential selection bias, we used a form of imputation suggested by Langkampt and others, where we redistributed the sample weights from missing samples to nonmissing samples based on covariate subgroups.[31] We first created subgroups based on all possible combinations of the differing covariates mentioned earlier, resulting in 300 possible subgroups. For each subgroup, we summed the weights from missing children in the stunting and diarrhea analyses, that is, children without anthropometry data and/or children that were not living, and then redistributed them equally to children that were in the sample.

Household ownership of livestock was defined as the number of the following animals owned: chickens, cows, goat, sheep, or pigs. Although most countries reported ownership of pigs as a country-specific variable, this animal species was not included in surveys from eight countries. An additional exposure of interest, based on research by Zambrano and others, was the presence of chickens and the number of chickens owned by the household.[8] The study results for chicken ownership are provided in the Supplemental Materials.

Covariates for the model were selected based on their potential to be confounding factors or strong predictors identified through existing literature. Covariates included mother's education, mother's age, improved water supply, safe treatment of water, improved sanitation, practice of open defecation, child's age, child's sex, number of members in household per sleeping room, number of children under 5 years of age in the household, and asset-based wealth. Breastfeeding was considered as a covariate but we found that it had a minor effect on our outcome variables. Water supply and sanitation facilities were recoded as improved and unimproved according to

United Nations Children's Fund/WHO Joint Monitoring Program for Water Supply and Sanitation definitions.[32]

To include a proxy for household wealth as a covariate, principal components analysis (PCA) was performed on rural households' assets for each country.[33,34] Household asset variables included electricity, radio, television, fridge, bicycle, motorbike, car, floor materials, wall materials, roof materials, stove type, watch, cart, boat, land, mobile phone, separate kitchen, and any other country-specific assets. As most variables were already binary, all household assets were converted to binary variables and a tetrachoric correlation for binary variables was used to produce appropriate weights.[35] Using the first principal component as a wealth score, all households were categorized into quintiles of wealth.

Statistical analysis.

Multivariable logistic regression was performed to estimate ORs. Animal ownership was $\log_2$ transformed, because we hypothesized that a logarithmic relationship between the number of animals owned (i.e., dose) and child health outcomes (i.e., response) would be likely. We chose $\log_2$ for ease of interpretation, so a one unit increase in $\log_2$ corresponds to a 2-fold increase in livestock ownership. ORs were interpreted as the outcome associated with a doubling in the number of animals owned. A recently published study using DHS data from Ethiopia, Kenya, and Uganda was used to inform this analysis.[36] All statistical analyses were conducted separately by country using the survey package in Stata 12 to specify the rural subpopulation, weights, strata, and clustering of primary sampling units. We performed the analysis at the child level as clustering at the primary sampling unit was sufficient to account for potential correlation between children within households. A meta-analysis with random effects using the Mantel–Haenszel method combined the final ORs to create a summary OR and demonstrate potential heterogeneity between countries. We reported the I^2 measure, which is the percentage of total variation across the effect estimates that is due to heterogeneity rather than chance, and a P value from the test for heterogeneity.[37]

Ethics statement.

DHS data collection activities were approved by the ICF International (Calverton, MD) institutional review board as well as the country-level entity that approves research on human subjects.[38]

RESULTS

Descriptive statistics using sample weights and the unweighted household sample sizes for all countries are reported in Table 1. Household ownership of animals, as well as chickens only, was heavily skewed to the right, thus means and medians are provided. Across all countries, the total unweighted sample size for rural children was 215,996 after removing 832 children missing data on certain covariates. We also calculated the total number of rural households affected by livestock ownership as the following for each country:

$$\frac{(\text{Total population size})\times(\%\,\text{rural households})\times(\%\,\text{rural households that own livestock})}{(\text{Mean rural household size})}$$

Population size data were obtained from the World Bank.[39] The total number of rural households that own livestock across all 30 countries is approximately 73 million. In all countries combined, the unweighted prevalence of livestock ownership, as defined previously, was 71% with a mean number of all animals owned at 13.7 (SD = 25.3) and median at 5 (interquartile range [IQR] = 0–16). The unweighted mean and median number of poultry owned overall was 6 (SD = 10.6) and 2 (IQR = 0–8), respectively. In the weighted statistics, 22 of 30 of the countries had ownership levels between 60% and 90%. Gabon had the lowest level of household livestock ownership at 37% and Burkina Faso the highest at 93%. The number of livestock and chickens was also greatest in Burkina Faso. The weighted mean wealth score, representing the quintile (1–5) of wealth categorized by PCA, ranged from 2.8 to 3.0 in all countries.

The unweighted sample sizes for the mortality, diarrhea, and stunting analyses were 215,971, 195,784, and 108,286, respectively (Table 2). Although the sample sizes differ, the statistics in Table 1 were very similar across samples. The sample sizes for the stunting analyses were much smaller for two possible reasons: 1) DHS randomly samples children for anthropometry in some countries and 2) anthropometry data can often be missing for children for various reasons. When we compared our results to those without the imputation, we found they were quite similar, suggesting little impact of selection bias by availability of anthropometry or child's vital status.

Stunting ranged from 21.1% in Namibia to 58.2% in Burundi (Table 2). Most of the countries (24 of 30) had between 30% and 50% of their children undernourished. In all countries but Namibia, the mean HAZ score was below −1.0, so many children were 1 SD under the height for their age according to WHO standards. The 2-week prevalence of diarrhea was the lowest at 6.4% in Benin and the highest at 26.0% in Burundi, where the stunting prevalence is also the greatest. Mortality was the greatest in Sierra Leone, where under-five mortality was 11.3%. Mortality was least common in Comoros at 4.7%.

We developed a conceptual diagram, based on evidence that identifies the potential causal pathways considered in this study (Figure 1). The diagram highlights relationships hypothesized and documented in the literature: 1) household wealth and education have been associated with WASH conditions,[40] 2) WASH has been found to impact child diarrhea and child growth,[14,41] and 3) nutrition and diarrhea have strong links to child mortality.[1,2]

The results from the adjusted logistic regressions for each child health indicator associated with a $\log_2$ increase in the number of livestock owned are displayed in Figure 2, with the actual numbers in Table 3. In Figure 2, the ORs are visualized by the direction of the OR (protective, null, or harmful) to illustrate overall patterns and concordance or discordance across indicators within each country. We categorized ORs within the range of 0.99–1.01 as null, those below 0.99 as protective and those above 1.01 as harmful. The unadjusted livestock results are reported in Supplemental Figures 1–3. The logistic regression results for chickens were very similar to the overall livestock results and are reported in the Supplemental Figures 4–6.

Animal ownership and stunting.

The ORs for stunting combined using a meta-analysis had an I^2 of 83.3% ($P < 0.001$) in the unadjusted models (Supplemental Table 1) and 39.8% ($P = 0.014$) after adjustment for the covariates described previously. After adjustment, many of the ORs were attenuated. The pooled OR indicated a slight protective effect for a $\log_2$ increase in the number of animals owned on stunting (OR = 0.98, 95% CI = 0.97, 0.99). Uganda displayed the most extreme adjusted OR less than 1 (OR = 0.88, 95% CI = 0.81, 0.96), illustrating a protective effect of livestock ownership. Approximately, two-thirds of the countries (22 of 30 countries) suggested a protective effect, though only four of those countries had CIs below 1. Six countries showed livestock ownership to be a risk for stunting, however, only one country, Nigeria, had a CI above 1 (OR = 1.03, 95% CI = 1.01, 1.06). For the 20 countries classified as having a protective effect, the pooled OR was 0.96 (95% CI = 0.95, 0.97).

Animal ownership and diarrhea.

For diarrhea, we also observed significant heterogeneity across countries ($I^2 = 40.9\%$, $P = 0.011$) in the adjusted models, but we did not see the same pattern in the ORs as we observed for stunting. Instead, we saw a somewhat even distribution with 10 of the countries demonstrating ORs < 1, seven close to null, and 13 ORs > 1. The most suggestive ORs were in Mali (OR = 0.94, 95% CI = 0.91, 0.98), Niger (OR = 0.95, 95% CI = 0.91, 0.99), Cameroon (OR = 1.06, 95% CI = 1.01, 1.12), and Mozambique (OR = 1.06, 95% CI = 1.01, 1.12). The pooled OR was essentially null (OR = 1.00, 95% CI = 0.99, 1.01). Overall, the results did not suggest a clear pattern of child diarrhea risk for households that own livestock. The pooled estimate for those 10 countries classified as exhibiting a protective effect was OR = 0.96 (95% CI = 0.95, 0.98), and the pooled estimate for those 13 countries classified as exhibiting a risk was OR = 1.03 (95% CI = 1.02, 1.05).

Animal ownership and child mortality.

The adjusted analyses for all-cause child mortality showed a pattern opposite to that of the stunting analyses. The overall I^2 for the adjusted analyses was 53.2% ($P < 0.001$). Approximately, two-thirds of the countries (22 of 30) displayed ORs > 1, of which nine had CIs above 1. The pooled OR also suggested livestock as a risk factor (OR = 1.04, 95% CI = 1.02, 1.06). In contrast, only one country, Kenya, displayed a strong protective effect of livestock toward mortality (OR = 0.90, 95% CI = 0.83, 0.99). The most extreme OR indicating livestock as a risk factor was in Liberia (OR = 1.20, 95% CI = 1.10, 1.29), suggesting a 20% increased odds of mortality associated with a doubling of livestock ownership. The pooled estimate of the 22 countries exhibiting livestock as a risk was OR = 1.06 (95% CI = 1.05, 1.08).

DISCUSSION

We analyzed small-scale livestock ownership as both a risk factor and a protective factor for child health outcomes including stunting, 2-week prevalence of diarrhea, and mortality in children less than 5 years of age in sub-Saharan Africa. Livestock ownership has been shown both to be associated with an increased risk of infection as well as health benefits through improved nutrition and socioeconomic status. Our multi-country analysis of livestock ownership and child morbidity and mortality agrees with this dual impact. Our analyses suggested a protective effect of livestock on the chronic condition of stunting in 22 of the 30 countries, a mixed effect on diarrhea (both associated with acute infection and chronic malnutrition), and a harmful effect on all-cause child mortality (potentially associated with acute infections) in 22 of the 30 countries, with all analyses displaying significant heterogeneity across countries.

On the one hand, livestock ownership may result in consumption of more nutrient dense food by children, and thus an explanation for our finding that livestock, as well as poultry ownership, on average was associated with less stunting in children. This finding is also in line with past research that identified a protective effect of household livestock ownership on child stunting prevalence in three east African countries.[36] It is possible that improved childhood nutrition improves immune function and offsets risk associated with exposure to enteric pathogens in animal feces.[42] Current evidence, however, suggests that animals are a risk factor for enteric infections and diarrhea.[8] Our results for diarrhea only somewhat reflect this evidence, with approximately a third of the countries suggesting an increased risk and a third suggesting a protective effect. Nonetheless, the finding that animal ownership had a positive association with child mortality may reflect this evidence. There is also the potential that other zoonotic infectious diseases (i.e., nonenteric infections) were responsible for the increased all-cause child mortality.

The strength of this analysis was its use of large, nationally representative data sets from 30 countries. DHS is a key source for measuring child mortality and undernutrition across LMICs. In the DHS, a complete birth and death history is collected for each eligible woman's children, including date of birth and, when applicable, age at death of each child. Further, the DHS has extensive training for enumerators and uses standardized measurement tools that include a core set of questions with pretesting to ensure that data are standardized and comparable across diverse settings. Spot checks and validation of completed surveys are regularly conducted as part of the DHS, but the quality of measurement also differs by country. A recent methodological report by DHS highlighted differences in quality of anthropometric measurements by country, which may explain some of the heterogeneity by country.[28]

The significant heterogeneity by country may also indicate country-specific dynamics in livestock practices that are not captured by DHS. Using the ownership of livestock variable, we could not ascertain whether the animals owned were kept near the household. For example, it may be that households own livestock but keep them at a location distant from where children are raised or that livestock were corralled rather than allowed to roam. The lack of detailed information on livestock management may lead to residual confounding that this analysis could not address. Also, it may be that livestock ownership under certain contexts is positively or negatively associated with poverty, which may have not been fully captured in our proxy measure for wealth. In this scenario, poverty, not animal ownership, could be the main risk factor for mortality. A study in Madagascar estimated that the burden of diseases among poultry exacerbated the economic impacts on poor households, leading to a 10–15% monthly income loss.[43] Although this could suggest wealth as a causal intermediate between livestock and child health, in our study, wealth was an asset-based index that did not incorporate livestock. Also, if this were true, however, we should have observed a similar relationship for stunting and diarrhea given that they have both been shown to have positive associations with poverty.

This analysis has other limitations. Results come from cross-sectional surveys, so longitudinal studies could strengthen our understanding of the relationship between livestock ownership and child health. The mortality analyses included any children that had died in the past 5 years of any cause, so the animal exposures identified in the surveys may not have reflected the child's actual exposure before their death. This situation could also apply to stunting given that it is a less acute health outcome and livestock exposures in the past may not be accurately reported by the household's livestock ownership at the time of the survey. A substantial change in livestock ownership by households, however, is also unlikely. Further, all-cause mortality is a fairly crude measure and includes a variety of causes that are unlikely to be influenced by livestock ownership. Selection bias for living children may be a concern for the stunting and diarrhea analyses; however, we examined this using a form of imputation and found little to no differences, which minimized selection bias from our observed variables. Finally, an important discussion in the context of the many analyses conducted in this article is multiple testing. We chose not to display *P* values for each country to focus more on the trends observed in each meta-analysis. We also advise against heavy reliance on the pooled estimates, especially given the significant heterogeneity observed across countries. Further, the DHS data were not designed to conduct an in-depth analysis of livestock ownership and health outcomes, so future studies should focus on what is happening within countries to improve our mechanistic understanding of the risks and protective effects of livestock.

Livestock ownership is highly prevalent in rural sub-Saharan Africa and other regions of the world. Furthermore, many development organizations provide livestock to households for poverty alleviation. The results of this article highlight the dual role of livestock and underscore the need to understand what aspects of livestock management are harmful or beneficial. Given the economic importance of livestock, it is surprising that few studies have emphasized both the protective and harmful effects on child health. More effort should be made to ascertain the mechanisms between livestock management practices and child health, and thereby better understand the country-level heterogeneity observed in the DHS data. This mechanistic understanding can provide direction for points of intervention in livestock management and related sanitary practices to mitigate risks and accentuate benefits.

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FIGURE 1. Conceptual diagram that includes covariates (orange), exposure variable of interest (livestock ownership), and health outcomes (red and black/white). Relationships noted may be positive or negative. Each number refers to a reference. This figure appears in color at www.ajtmh.org.

FIGURE 2. Adjusted odds ratios for each child health indicator across countries in sub-Saharan Africa categorized as significantly protective (dark green), protective (green), null (yellow), harmful (red), and significantly harmful (dark red). *Adjusted for mother's education and age, improved water supply, safe treatment of water, improved sanitation, open defecation, child's age and sex, household members per sleeping room, children in the household, and asset wealth. This figure appears in color at www.ajtmh.org.

TABLE 1

Descriptive characteristics for rural HHs in sub-Saharan Africa based on DHS data including HHs with livestock (calculated using the total population size according to the World Bank)

	Survey year	HHs in sample (*N*)	Livestock ownership (%)	HHs with livestock '000	Animals* per HH (mean [SD])	Animals* per HH (med. [IQR])	Chickens per HH (mean [SD])	Chickens per HH (med. [IQR])
Benin	2011–2012	5,084	40	460	9.9 (22.6)	0 (0–11)	5.8 (13.3)	0 (0–6)
Burkina Faso	2010	6,345	93	2,070	41.2 (42.7)	14 (29–53)	12.8 (14.2)	3 (10–20)
Burundi	2010	3,924	62	1,250	3.4 (5)	0 (2–5)	1 (2.5)	0 (0–1)
Cameroon	2011	3,648	70	1,460	11 (17.4)	0 (5–14)	5.5 (9.5)	0 (2–8)
Comoros	2012	1,223	50	50	4.2 (7.1)	0 (0–6)	1.6 (3.7)	0 (0–1)
Congo	2011	4,205	44	180	5.5 (13.8)	0 (0–8)	4.6 (11.5)	0 (0–7)
Congo DR	2013–2014	7,320	56	5,250	3.9 (6.7)	0 (1–6)	2.8 (4.9)	0 (0–4)
Cote d'Ivoire	2011–2012	2,850	47	1,030	7.8 (15.8)	0 (0–10)	5.6 (12.6)	0 (0–6)
Ethiopia	2011	6,043	92	13,940	8.6 (8.6)	3 (6–11)	3 (4.2)	0 (2–4)
Gabon	2012	1,271	37	30	5 (16.5)	0 (0–7)	4.6 (15.4)	0 (0–6)
Ghana	2008	1,291	64	2,190	11.3 (17.7)	0 (5–16)	7.5 (12.2)	0 (3–10)
Guinea	2012	2,796	69	900	9.9 (14.3)	0 (5–13)	4.3 (6.9)	0 (0–6)
Kenya	2008–2009	2,854	83	6,090	11.6 (19.2)	2 (6–14)	5.1 (7.3)	0 (3–7)
Lesotho	2009	2,355	66	250	11.9 (25.8)	0 (4–12)	2.3 (5.3)	0 (0–3)
Liberia	2013	3,065	53	200	5.6 (11.8)	0 (1–8)	4.7 (10.1)	0 (0–6)
Madagascar	2008–2009	6,535	75	3,130	8.8 (12.6)	1 (5–12)	5.6 (8)	0 (3–8)
Malawi	2010	11,837	67	2,010	7.7 (11.6)	0 (4–11)	5.9 (9.4)	0 (2–8)
Mali	2012–2013	4,375	75	1,640	31.6 (43)	0 (16–40)	6.7 (12.5)	0 (0–10)
Mozambique	2011	4,628	66	2,860	7.9 (12)	0 (4–11)	5.7 (8.3)	0 (3–8)
Namibia	2013	1,785	75	180	29.3 (43.2)	0 (16–40)	9 (11.7)	0 (6–13)
Niger	2012	4,992	80	2,100	8.8 (11.7)	1 (5–12)	3 (5.4)	0 (0–4)
Nigeria	2013	11,327	73	15,200	15.6 (23.5)	0 (8–21)	7.6 (12.3)	0 (3–10)
Rwanda	2010–2011	5,280	58	1,350	2.1 (3.3)	0 (1–3)	0.7 (2)	0 (0–0)
Senegal	2010–2011	3,539	81	590	23.1 (40.3)	2 (11–27)	6.6 (11.3)	0 (3–10)

Sierra Leone	2013	4,829	63	450	6.8 (11.6)	0 (3–10)	5.2 (7.5)	0 (2–8)
Swaziland	2006–2007	1,292	79	130	19.4 (20.2)	3 (13–28)	11.3 (11.7)	1 (9–17)
Togo	2013–2014	3,014	76	580	17.8 (25.2)	1 (10–25)	12.1 (17.4)	0 (6–20)
Uganda	2011	3,515	72	4,430	7 (10.1)	0 (4–9)	3.7 (6.3)	0 (1–5)
Zambia	2007	2,484	76	1,550	10.5 (14.3)	1 (6–14)	7.2 (9.5)	0 (4–10)
Zimbabwe	2010–2011	2,860	79	1,770	12.6 (15.1)	2 (8–18)	8.3 (10.6)	0 (5–12)

DHS = Demographic and Health Survey; HH = household; IQR = interquartile range; med. = median; SD = standard deviation.

* Animals include chickens, cows, goat, sheep, or pigs per HH.

TABLE 2

Unweighted sample sizes of analyses and weighted statistics of child health indicators

	Stunting sample (*N*)	Stunting (%)	HAZ (mean [SD])	Diarrhea sample (*N*)	Diarrhea (%)	Mortality sample (*N*)	Mortality (%)
Benin	4,828	43.9	–1.5 (2.2)	7,897	6.4	8,470	5.7
Burkina Faso	5,064	36.1	–1.4 (1.5)	10,539	15.0	11,741	9.6
Burundi	2,831	58.2	–2.2 (1.2)	5,878	26.0	6,348	7.2
Cameroon	2,925	38.7	–1.4 (1.6)	6,085	24.4	6,995	10.0
Comoros	1,587	29.8	–1.2 (1.8)	1,914	17.3	2,059	4.7
Congo	3,333	28.8	–1.2 (1.7)	6,461	15.2	6,911	4.8
Congo DR	5,677	45.1	–1.7 (1.7)	11,922	16.5	13,148	7.8
Cote d'Ivoire	2,109	32.6	–1.3 (1.4)	4,537	18.0	5,145	8.9
Ethiopia	8,038	43.8	–1.6 (1.7)	8,847	14.4	9,633	7.1
Gabon	1,304	27.0	–1.1 (1.9)	2,066	18.2	2,335	6.3
Ghana	1,582	29.9	–1.1 (1.7)	1,830	21.6	1,985	6.3
Guinea	2,209	33.2	–1.2 (1.7)	4,430	16.9	4,987	9.8
Kenya	3,910	35.5	–1.4 (1.5)	4,265	17.0	4,605	6.4
Lesotho	1,398	36.9	–1.4 (1.6)	2,927	12.1	3,327	10.8
Liberia	2,165	30.3	–1.3 (1.6)	4,641	24.9	5,176	7.0
Madagascar	3,964	49.3	–1.8 (1.8)	9,445	8.2	10,195	5.7
Malawi	4,116	46.3	–1.7 (1.6)	16,460	18.1	18,013	8.4
Mali	3,250	39.4	–1.5 (1.7)	7,124	8.7	7,801	7.8
Mozambique	6,367	44.6	–1.7 (1.6)	6,861	11.0	7,494	7.6
Namibia	908	21.1	–0.9 (1.3)	2,439	21.3	2,736	4.8
Niger	3,720	44.7	–1.7 (1.5)	8,809	14.4	9,766	8.6
Nigeria	15,890	42.3	–1.6 (2.0)	18,609	11.3	20,999	10.4
Rwanda	3,514	44.3	–1.8 (1.3)	7,250	13.4	7,721	5.9
Senegal	2,495	30.3	–1.2 (1.5)	7,943	19.6	8,681	6.0
Sierra Leone	2,889	39.2	–1.4 (1.7)	7,073	11.3	8,217	11.3
Swaziland	1,605	26.8	–1.1 (1.4)	1,837	15.8	2,084	9.2
Togo	2,303	30.7	–1.3 (1.4)	4,591	17.9	4,975	7.0
Uganda	1,639	35.7	–1.5 (1.4)	5,630	24.7	6,192	7.0
Zambia	3,481	45.7	–1.7 (1.7)	3,868	15.3	4,280	8.5
Zimbabwe	3,185	31.8	–1.3 (1.4)	3,606	12.9	3,952	6.9

HAZ = height-for-age *z* score; SD = standard deviation.

TABLE 3

ORs, CIs, and meta-analysis weights for the association of a log_2 increase in animal ownership with each child health indicator

Country	Stunting			Diarrhea			All-cause mortality		
	OR	95% CI	Weight	OR	95% CI	Weight	OR	95% CI	Weight
Uganda	0.88	0.81, 0.96	1.72	0.98	0.93, 1.03	3.46	1.02	0.95, 1.10	3.34
Kenya	0.93	0.89, 0.98	3.42	1.02	0.96, 1.09	2.70	0.90	0.83, 0.99	2.46
Rwanda	0.94	0.87, 1.02	1.81	1.00	0.93, 1.08	2.18	0.97	0.87, 1.09	1.85
Lesotho	0.95	0.89, 1.01	2.36	1.04	0.97, 1.11	2.50	1.01	0.93, 1.10	2.88
Madagascar	0.95	0.91, 0.99	4.20	1.03	0.97, 1.08	3.22	1.05	0.99, 1.11	3.95
Namibia	0.96	0.88, 1.04	1.72	0.95	0.90, 1.00	3.58	1.03	0.95, 1.12	2.62
Swaziland	0.96	0.89, 1.03	2.16	0.96	0.88, 1.05	1.55	0.96	0.87, 1.06	2.27
Mozambique	0.96	0.93, 0.99	5.02	1.06	1.01, 1.12	3.27	1.08	1.01, 1.15	3.63
Comoros	0.97	0.89, 1.05	1.67	1.02	0.93, 1.13	1.46	1.04	0.86, 1.25	0.79
Sierra Leone	0.97	0.92, 1.01	3.57	1.04	0.98, 1.11	2.85	1.04	0.98, 1.09	4.32
Ethiopia	0.97	0.92, 1.01	3.86	0.95	0.90, 1.01	2.84	0.96	0.87, 1.05	2.26
Ghana	0.97	0.91, 1.04	2.14	1.00	0.93, 1.07	2.28	0.94	0.84, 1.06	1.70
Zimbabwe	0.97	0.92, 1.02	3.49	1.04	0.98, 1.11	2.57	1.01	0.93, 1.09	3.02
Cote d’Ivoire	0.97	0.92, 1.03	2.76	0.98	0.93, 1.04	3.37	1.06	0.98, 1.13	3.27
Congo DR	0.98	0.93, 1.02	3.64	1.00	0.95, 1.06	3.12	1.08	1.00, 1.17	2.82
Malawi	0.98	0.93, 1.02	3.56	0.98	0.95, 1.01	5.49	1.01	0.96, 1.06	4.71
Liberia	0.98	0.92, 1.05	2.34	1.03	0.98, 1.07	4.15	1.20	1.10, 1.29	2.89
Burkina Faso	0.98	0.94, 1.02	4.21	1.00	0.96, 1.04	4.74	1.06	1.01, 1.11	4.73
Niger	0.98	0.94, 1.03	3.95	0.95	0.91, 0.99	4.21	1.08	1.02, 1.13	4.48
Burundi	0.99	0.92, 1.05	2.24	0.98	0.92, 1.03	2.98	1.00	0.91, 1.10	2.37
Zambia	0.99	0.94, 1.03	3.58	1.03	0.97, 1.10	2.72	0.98	0.91, 1.05	3.19
Cameroon	0.99	0.95, 1.04	3.61	1.06	1.01, 1.12	3.42	1.08	1.03, 1.13	4.73
Benin	1.00	0.97, 1.03	5.81	1.00	0.95, 1.05	3.46	1.08	1.04, 1.14	4.73
Togo	1.00	0.95, 1.05	3.47	1.03	0.98, 1.08	3.44	1.08	1.01, 1.16	3.44
Senegal	1.01	0.96, 1.06	3.70	1.00	0.97, 1.04	5.10	1.04	0.99, 1.10	4.48
Guinea	1.01	0.95, 1.07	3.01	1.04	0.99, 1.09	3.44	1.08	1.01, 1.16	3.42
Congo	1.02	0.97, 1.07	3.57	1.01	0.96, 1.05	4.20	1.02	0.94, 1.12	2.61
Mali	1.02	0.99, 1.06)	4.87	0.94	0.91, 0.98	4.39	0.99	0.95, 1.03	4.99
Nigeria	1.03	1.01, 1.06)	6.43	1.02	0.98, 1.05	5.40	1.03	1.00, 1.06	5.93
Gabon	1.04	0.97, 1.11)	2.10	0.94	0.86, 1.01	1.91	1.16	1.05, 1.29	2.13
Pooled OR	0.98	0.97, 0.99)		1.00	0.99, 1.01		1.04	1.02, 1.06	

CI = confidence interval; OR = odds ratio. Adjusted for mother’s education and age, improved water supply, safe treatment of water, improved sanitation, open defecation, child’s age and sex, household members per sleeping room, children in the household, and asset wealth.

SUPPLEMENTAL FIGURE 1. Unadjusted odds ratio for stunting associated with livestock owned.

SUPPLEMENTAL FIGURE 2. Unadjusted odds ratio for diarrhea associated with livestock.

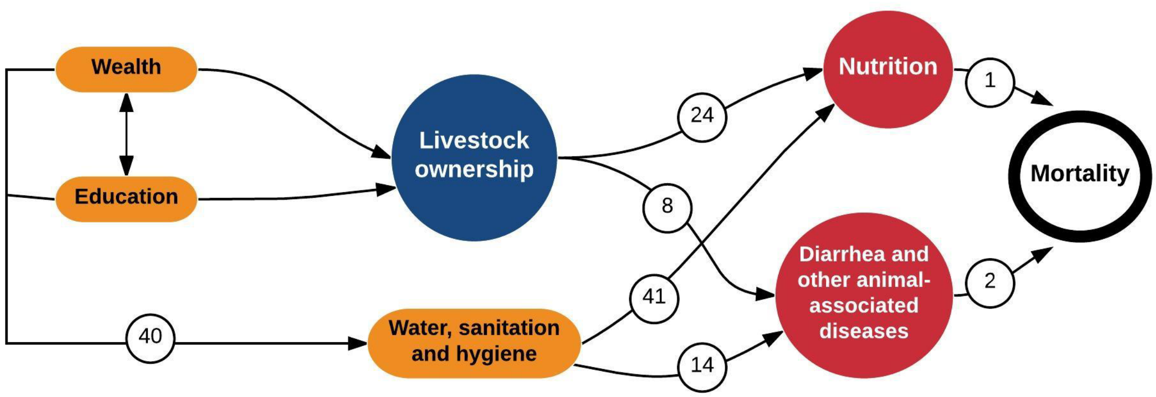
SUPPLEMENTAL FIGURE 3. Unadjusted odds ratio for mortality associated with livestock.

SUPPLEMENTAL Figure 4. (**A**) Unadjusted odds ratios (ORs) for stunting associated with chickens. (**B**) Adjusted ORs for stunting associated with chickens.

SUPPLEMENTAL FIGURE 5. (**A**) Unadjusted odds ratios (ORs) for diarrhea associated with chickens. (**B**) Adjusted ORs for diarrhea associated with chickens.

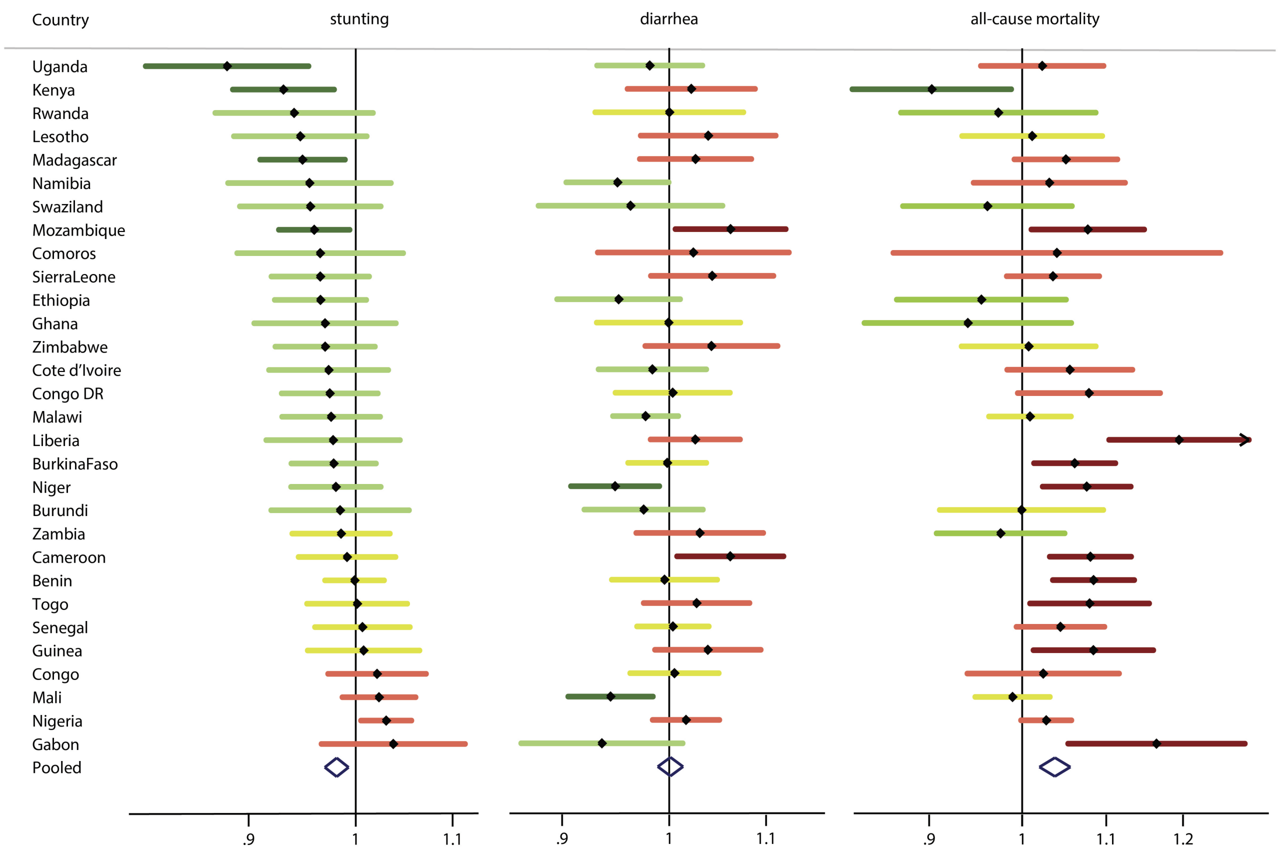
SUPPLEMENTAL FIGURE 6. (**A**) Unadjusted odds ratios (ORs) for mortality associated with chickens. (**B**) Adjusted ORs for mortality associated with chickens.

Figure 1



Wealth
Education
Livestock ownership
Water, sanitation and hygiene
Nutrition
Diarrhea and other animal-associated diseases
Mortality
1
2
8
14
24
40
41

Figure 2



Country
stunting
diarrhea
all-cause mortality
Uganda
Kenya
Rwanda
Lesotho
Madagascar
Namibia
Swaziland
Mozambique
Comoros
SierraLeone
Ethiopia
Ghana
Zimbabwe
Cote d'Ivoire
Congo DR
Malawi
Liberia
BurkinaFaso
Niger
Burundi
Zambia
Cameroon
Benin
Togo
Senegal
Guinea
Congo
Mali
Nigeria
Gabon
Pooled
.9
1
1.1
.9
1
1.1
.9
1
1.1
1.2

Figure S1

Figure S1. Unadjusted OR for stunting associated with livestock

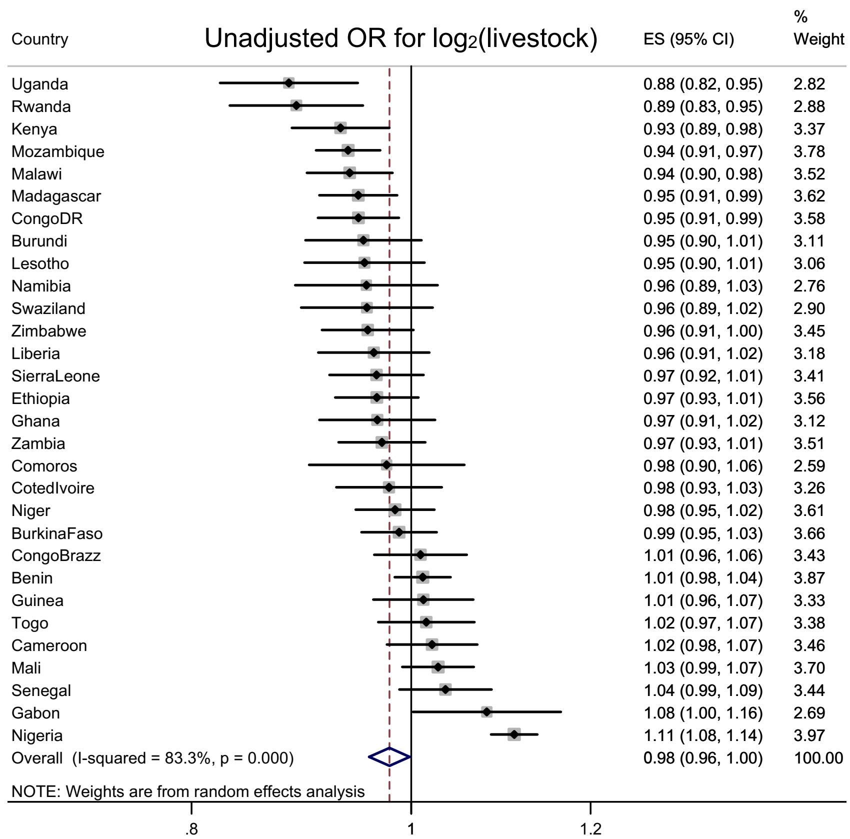


Figure S2

Figure S2. Unadjusted OR for diarrhea associated with livestock

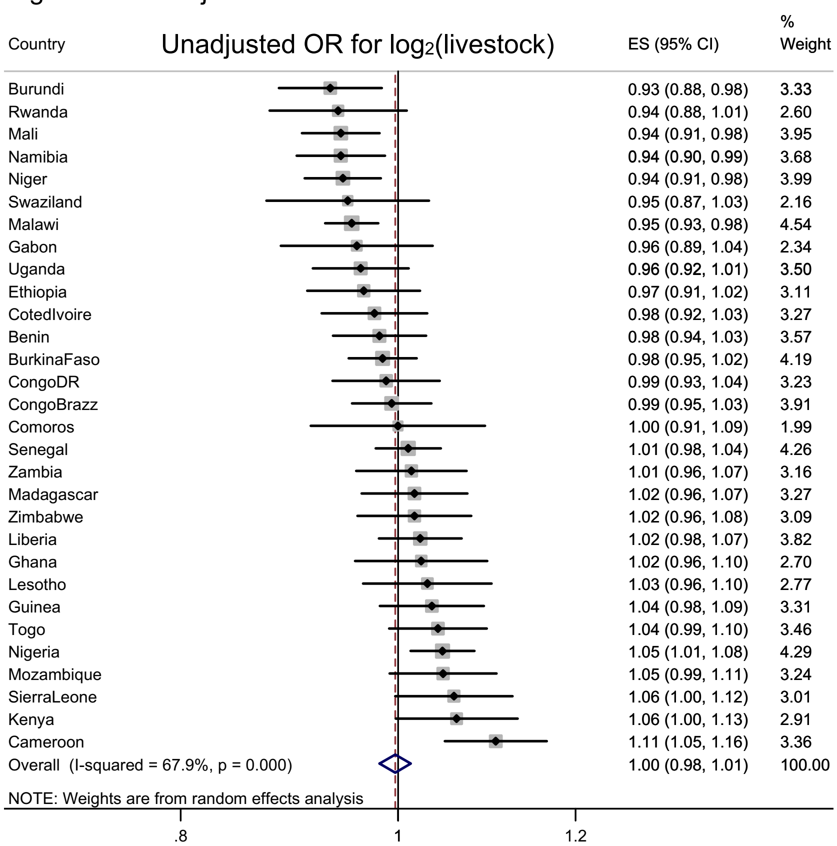
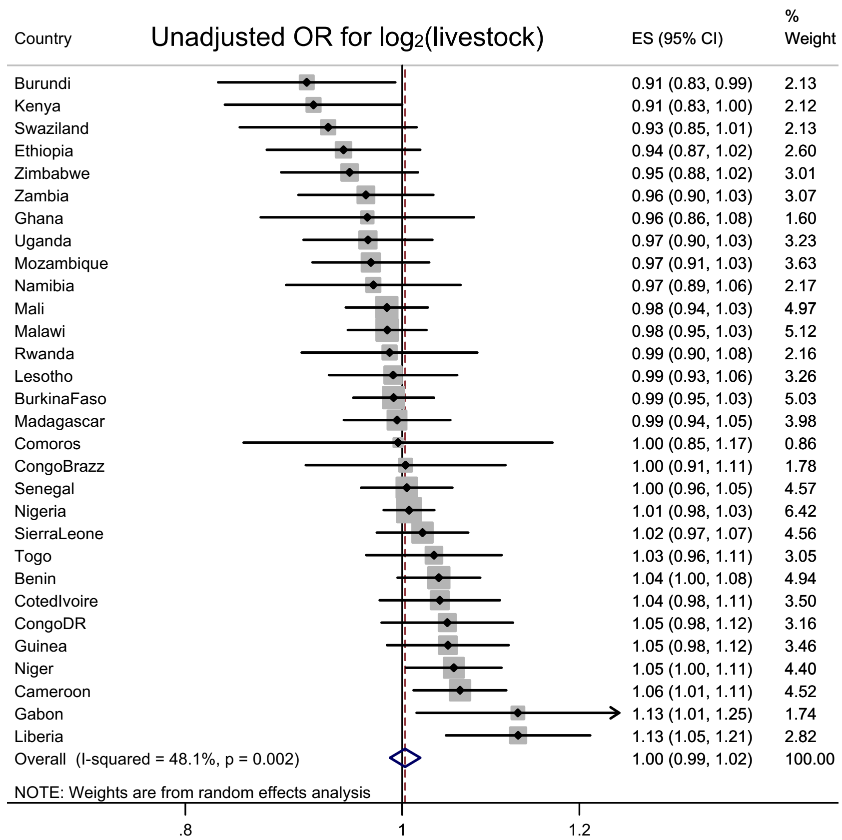


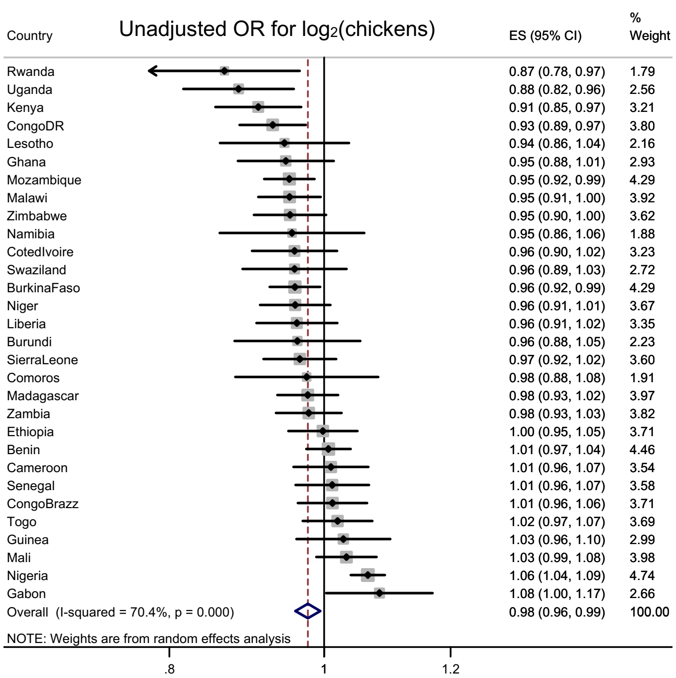
Figure S3



Country
Unadjusted OR for $\log_2$(livestock)
ES (95% CI)
% Weight
Burundi 0.91 (0.83, 0.99) 2.13
Kenya 0.91 (0.83, 1.00) 2.12
Swaziland 0.93 (0.85, 1.01) 2.13
Ethiopia 0.94 (0.87, 1.02) 2.60
Zimbabwe 0.95 (0.88, 1.02) 3.01
Zambia 0.96 (0.90, 1.03) 3.07
Ghana 0.96 (0.86, 1.08) 1.60
Uganda 0.97 (0.90, 1.03) 3.23
Mozambique 0.97 (0.91, 1.03) 3.63
Namibia 0.97 (0.89, 1.06) 2.17
Mali 0.98 (0.94, 1.03) 4.97
Malawi 0.98 (0.95, 1.03) 5.12
Rwanda 0.99 (0.90, 1.08) 2.16
Lesotho 0.99 (0.93, 1.06) 3.26
BurkinaFaso 0.99 (0.95, 1.03) 5.03
Madagascar 0.99 (0.94, 1.05) 3.98
Comoros 1.00 (0.85, 1.17) 0.86
CongoBrazz 1.00 (0.91, 1.11) 1.78
Senegal 1.00 (0.96, 1.05) 4.57
Nigeria 1.01 (0.98, 1.03) 6.42
SierraLeone 1.02 (0.97, 1.07) 4.56
Togo 1.03 (0.96, 1.11) 3.05
Benin 1.04 (1.00, 1.08) 4.94
CotedIvoire 1.04 (0.98, 1.11) 3.50
CongoDR 1.05 (0.98, 1.12) 3.16
Guinea 1.05 (0.98, 1.12) 3.46
Niger 1.05 (1.00, 1.11) 4.40
Cameroon 1.06 (1.01, 1.11) 4.52
Gabon 1.13 (1.01, 1.25) 1.74
Liberia 1.13 (1.05, 1.21) 2.82
Overall (I-squared = 48.1%, p = 0.002) 1.00 (0.99, 1.02) 100.00
NOTE: Weights are from random effects analysis
.8
1
1.2

Figure S4

A Unadjusted OR's for stunting associated with chickens



B Adjusted OR's for stunting associated with chickens

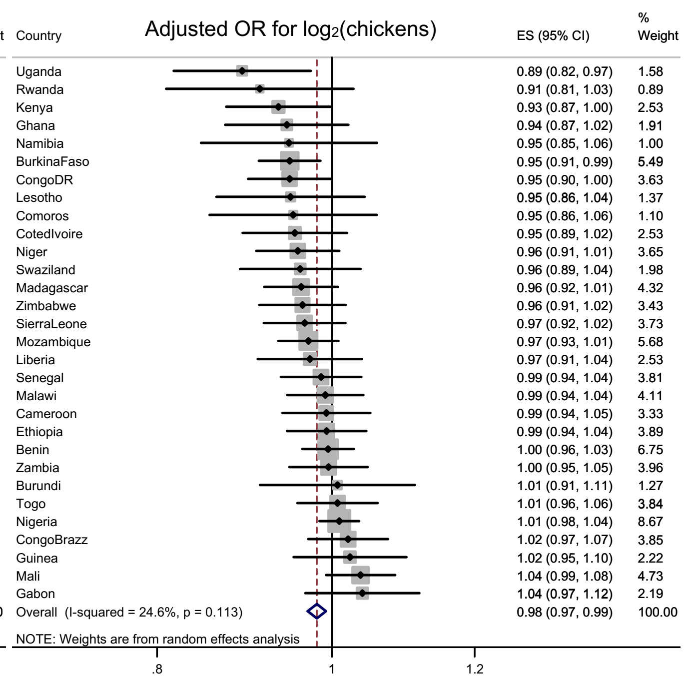


Figure S5

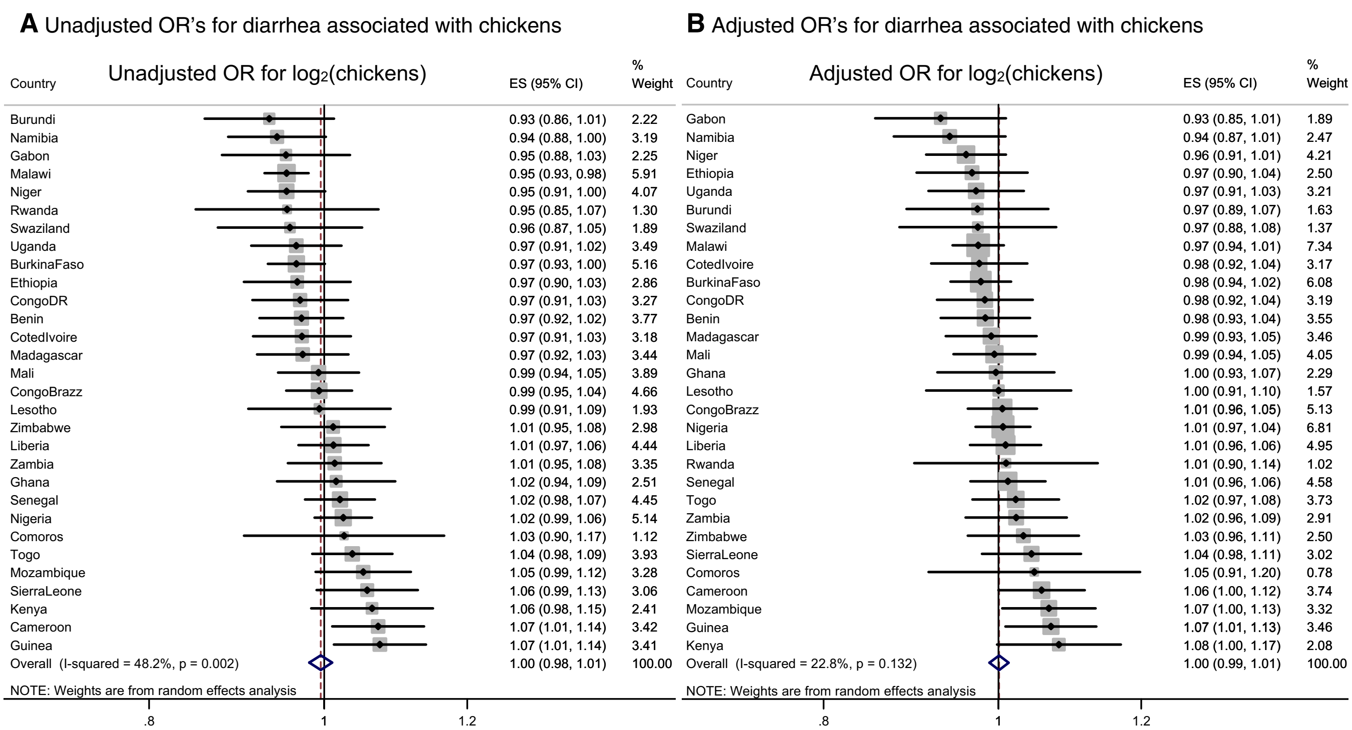

A Unadjusted OR's for diarrhea associated with chickens
Unadjusted OR for log2(chickens)
Country
ES (95% CI)
% Weight
Burundi 0.93 (0.86, 1.01) 2.22
Namibia 0.94 (0.88, 1.00) 3.19
Gabon 0.95 (0.88, 1.03) 2.25
Malawi 0.95 (0.93, 0.98) 5.91
Niger 0.95 (0.91, 1.00) 4.07
Rwanda 0.95 (0.85, 1.07) 1.30
Swaziland 0.96 (0.87, 1.05) 1.89
Uganda 0.97 (0.91, 1.02) 3.49
BurkinaFaso 0.97 (0.93, 1.00) 5.16
Ethiopia 0.97 (0.90, 1.03) 2.86
CongoDR 0.97 (0.91, 1.03) 3.27
Benin 0.97 (0.92, 1.02) 3.77
CotedIvoire 0.97 (0.91, 1.03) 3.18
Madagascar 0.97 (0.92, 1.03) 3.44
Mali 0.99 (0.94, 1.05) 3.89
CongoBrazz 0.99 (0.95, 1.04) 4.66
Lesotho 0.99 (0.91, 1.09) 1.93
Zimbabwe 1.01 (0.95, 1.08) 2.98
Liberia 1.01 (0.97, 1.06) 4.44
Zambia 1.01 (0.95, 1.08) 3.35
Ghana 1.02 (0.94, 1.09) 2.51
Senegal 1.02 (0.98, 1.07) 4.45
Nigeria 1.02 (0.99, 1.06) 5.14
Comoros 1.03 (0.90, 1.17) 1.12
Togo 1.04 (0.98, 1.09) 3.93
Mozambique 1.05 (0.99, 1.12) 3.28
SierraLeone 1.06 (0.99, 1.13) 3.06
Kenya 1.06 (0.98, 1.15) 2.41
Cameroon 1.07 (1.01, 1.14) 3.42
Guinea 1.07 (1.01, 1.14) 3.41
Overall (I-squared = 48.2%, p = 0.002) 1.00 (0.98, 1.01) 100.00
NOTE: Weights are from random effects analysis
.8
1
1.2
B Adjusted OR's for diarrhea associated with chickens
Adjusted OR for log2(chickens)
Country
ES (95% CI)
% Weight
Gabon 0.93 (0.85, 1.01) 1.89
Namibia 0.94 (0.87, 1.01) 2.47
Niger 0.96 (0.91, 1.01) 4.21
Ethiopia 0.97 (0.90, 1.04) 2.50
Uganda 0.97 (0.91, 1.03) 3.21
Burundi 0.97 (0.89, 1.07) 1.63
Swaziland 0.97 (0.88, 1.08) 1.37
Malawi 0.97 (0.94, 1.01) 7.34
CotedIvoire 0.98 (0.92, 1.04) 3.17
BurkinaFaso 0.98 (0.94, 1.02) 6.08
CongoDR 0.98 (0.92, 1.04) 3.19
Benin 0.98 (0.93, 1.04) 3.55
Madagascar 0.99 (0.93, 1.05) 3.46
Mali 0.99 (0.94, 1.05) 4.05
Ghana 1.00 (0.93, 1.07) 2.29
Lesotho 1.00 (0.91, 1.10) 1.57
CongoBrazz 1.01 (0.96, 1.05) 5.13
Nigeria 1.01 (0.97, 1.04) 6.81
Liberia 1.01 (0.96, 1.06) 4.95
Rwanda 1.01 (0.90, 1.14) 1.02
Senegal 1.01 (0.96, 1.06) 4.58
Togo 1.02 (0.97, 1.08) 3.73
Zambia 1.02 (0.96, 1.09) 2.91
Zimbabwe 1.03 (0.96, 1.11) 2.50
SierraLeone 1.04 (0.98, 1.11) 3.02
Comoros 1.05 (0.91, 1.20) 0.78
Cameroon 1.06 (1.00, 1.12) 3.74
Mozambique 1.07 (1.00, 1.13) 3.32
Guinea 1.07 (1.01, 1.13) 3.46
Kenya 1.08 (1.00, 1.17) 2.08
Overall (I-squared = 22.8%, p = 0.132) 1.00 (0.99, 1.01) 100.00
NOTE: Weights are from random effects analysis
.8
1
1.2

Figure S6

A Unadjusted OR's for mortality associated with chickens

B Adjusted OR's for mortality associated with chickens