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Household, Community and District clustering of trachoma, and the Protective Impact of Latrines

in 11 Health Districts in Guinea

By

Jonathan M. Bressler
Master of Public Health

Global Epidemiology

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Matthew C. Freeman
Committee Chair

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B.S., University of Illinois at Urbana-Champaign, 2008

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Abstract

Household, Community and District Clustering of Trachoma, and the Protective Impact of Latrines in 11 Health Districts in Guinea

By Jonathan M. Bressler

Background: Trachoma—a disease caused by an entirely preventable bacterial infection—has made 1.2 million people alive today irreversibly blind. An international coalition of partners has taken on the goal of eliminating preventable blindness due to trachoma from the world by 2020. For the past fifteen years, the World Health Organization (WHO) has recommended the SAFE strategy to achieve this ambitious goal. Progress in sanitation under the "environmental change" element of this strategy has been slow, and the role that household waste facilities play in preventing this disease is unclear. During baseline mapping of trachoma in 11 health districts in Guinea in 2012 and 2013, concurrent household surveys were conducted to assess water and sanitation factors in all households surveyed for trachoma. We conducted a robust secondary analysis of these data in an effort to quantify on a large scale the impact that latrines have on trachoma.

Methods: Using mixed-effects logistic and linear models, we assessed the impact of latrine use and latrine cleanliness on active trachoma in 1-9 year old children, and the impact of community-wide latrine coverage on trachoma prevalence.

Principal Findings: 4,767 households with 22,954 children between 1 and 9 years of age were surveyed in all 11 health districts. After adjusting for clustering and other factors, we found that children in households with clean, well-maintained latrines were almost two-thirds as likely to have TF or TI as children without latrines or with poorly maintained latrines (POR 0.69, 95%CI 0.60 – 0.80). However, children in households that merely used latrines, regardless of latrine cleanliness, did not show a statistically significant difference in TF or TI from those in households with no latrine. Furthermore, community-wide increases in both latrine use and latrine cleanliness were significantly associated with community TF/TI prevalence below 5%, indicating that latrines are highly associated with maintaining trachoma burden below potentially blinding levels.

Conclusion: Latrine cleanliness is extremely important to reduction of the burden of trachoma, and merely owning and using a latrine is not necessarily protective. High latrine coverage will be necessary to bringing trachoma prevalence below blinding levels, and keeping it low post-elimination.

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Household, Community and District Clustering of Trachoma, and the Protective Impact of Latrines in 11 Health Districts in Guinea

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Introduction

Approximately 2.2 million people worldwide are visually impaired due to trachoma, 1.2 million of whom are irreversibly blind (Pascolini *et al.* 2012; WHO 2013). Over three-quarters of the world's 229 million people living in trachoma-endemic areas are in Africa (ICTC 2013; Stocks *et al.* 2014). Trachoma is completely preventable, yet it is the leading infectious cause of blindness worldwide (ICTC 2013). The disease is caused by ocular infection of the *C. trachomatis* bacteria. Infection causes inflammation of the eyelid called "trachomatous inflammation," and over decades of repeated infection leads to inversion of the eyelid such that the eyelashes turn inward, a condition called "trichiasis." Without corrective surgery the lashes begin to scratch the cornea, causing incessant pain, to the point of visual impairment and eventual blindness (ICTC 2013). Blindness does not just cause complete loss of independence and productivity in otherwise healthy individuals—it puts an additional burden on families who must care for blind family members and give up their own time to do so (ICTC 2013). Approximately 334,000 disability-adjusted life years are attributed to trachoma worldwide (Murray *et al.* 2013).

The World Health Organization (WHO) supports the SAFE strategy for elimination of blindness due to trachoma by 2020: "surgery" for trichiasis, mass distribution of the "antibiotics" azithromycin and tetracycline, "facial cleanliness", and "environmental change", including better water access and access to sanitation facilities (WHO 1998; WHO 2003). Surgery to reverse trichiasis and annual mass treatment with the antibiotic azithromycin is recommended in all districts endemic for trachoma. Trachoma is considered endemic in areas where the prevalence of trachomatous inflammation - follicular (TF) in 1-9 year-olds is over 10% or where the prevalence of trachomatous trichiasis (TT) is over 0.1% in people 15 or older, and targeted treatment is recommended in communities where the prevalence is between 5% and 10% (Solomon *et al.* 2006). Through sustained donation of azithromycin by Pfizer, Inc the number of annual doses has been scaled up from 1 million in 1998 to 47.8 million in 2012, and over 30 countries have implemented some form of trachoma control program.

While considerable gains have been made under the S and A portions of the strategy, elimination of blinding trachoma cannot succeed until the F and E components are fully implemented (Emerson *et al.* 2000; Hu *et al.* 2010; Emerson *et al.* 2012). Though there is some evidence to suggest that clean faces and presence of sanitation are associated with lower risk of trachomatous inflammation (Stocks *et al.* 2014), the rigorous evidence as demonstrated using experimental trials is limited (Rabiu *et al.* 2012; Ejere *et al.* 2012). Facial cleanliness interventions include health education sessions in villages, radio messaging and others. Environmental changes proposed to reduce the burden of trachoma include the promotion of toilet construction and use, and construction of clean water sources where access to such sources is limited. Construction of toilets, when properly and hygienically maintained and used, remove feces from the environment, and thus reduce the number of potential breeding sites for eye-seeking flies that can serve as a vector for transmission (Emerson *et al.* 2004). Yet, interventions that address these factors and are considerably more involved and expensive to implement than surgery and antibiotics, and collaboration between the WASH and NTD sectors has presented a challenge (Freeman *et al.* 2013), perhaps explaining the dearth of F and E interventions in trachoma control programs.

The presence of toilet facilities and their use likely influences trachoma prevalence at both the household and community level. In households, toilets remove feces from the immediate environment and thus remove breeding sites for eye-seeking flies. Flies may still breed, however, near other households that lack latrines, maintaining the vector in communities until latrine use is very high community-wide.

Population-based prevalence surveys are considered the ‘gold standard’ for assessing the countrywide burden of trachoma (Wright *et al.* 2005), and are useful to trachoma control programs for allocating resources for maximum impact. In these surveys, health districts are the primary sampling unit, from which communities, then households, are selected randomly. This method accurately measures disease prevalence district-wide, but does not necessarily capture the variation in disease across all areas of a district, since prevalence may vary greatly from one community to the next. Trachoma transmission is also highly clustered within communities and households (Burton 2007; Katz *et al.* 1988; Tielsch *et al.* 1988; Mabey *et al.* 1992), indicating that prolonged and frequent contact between individuals is necessary for transmission (Emerson *et al.* 2000). Studies have shown that sleeping in a room with an active case elevates the risk of trachoma (Bailey *et al.* 1989; Courtright *et al.* 1991; West *et al.* 1991), while crowding has proven a risk factor in some cases (Assaad *et al.* 1968; Barenfanger 1975) but not a factor in others (Bailey *et al.* 1989).

In Guinea, trachoma is particularly problematic in the upper and middle regions of the north and east, which border the sahelian regions of Senegal, Mali, and Côte d’Ivoire and are somewhat drier in comparison to the coastal and forest regions of the country. Surveys conducted from 2011 to 2013 revealed a baseline prevalence of trachomatous inflammation among 1-9 year-olds of over 30% in 5 health districts and between 5% and 10% in 4 health districts of the 18 health districts in the upper and middle regions of the country (unpublished data, Ministry of Health of Guinea). During years 2012 and 2013 of these prevalence surveys, an additional household survey was conducted concurrently to assess the access to water and sanitation facilities in 11 health districts of the upper, middle and forest regions.

The goal of this study was to assess the effect of latrine use and cleanliness on the prevalence of active trachoma, and to evaluate the degree of clustering of the disease at the household, community, and district levels. Using data collected during trachoma prevalence mapping in 2012 and 2013, we assessed the effect of (a) household latrine use, and (b) household latrine cleanliness on TF/TI in 1-9 year-olds and on community TF/TI prevalence. We also evaluated the degree of clustering of active trachoma within households, communities, and districts while adjusting for these and other relevant factors. The purpose of this research was to quantify the role of latrine use and cleanliness, and local clustering of disease on the prevalence of trachoma.

Methods

Study Context

Trachoma prevalence surveys and the concurrent household water and sanitation surveys were conducted by the Ministry of Health of Guinea in 2012 in the health districts of Koundara and Yomou, and in 2013 in the districts of Gaoual, Mali, Koubia, Tougue, Sigiri, Mandiana, Kankan, Kerouane and Beyla. The population in these areas lives predominantly in rural villages and survives on subsistence farming. The district-level prevalence of TF in 1 to 9 year-olds in these areas ranged from an estimated 1% in Yomou to 25% in Kankan (unpublished data, Ministry of Health of Guinea), while individual sub-districts showed prevalences lower than 1% and even greater than 30%. The combined population of these areas is estimated to be about 3.06

million (INS de la Guinée 2014). Since completing prevalence mapping of these districts, the Ministry of Health and its partners have been conducting mass drug administration with azithromycin for adults and children and tetracycline ointment for infants, and trichiasis surgeries in support of the effort to eliminate blinding trachoma by 2020 (ICTC 2011). Although projects to build latrines and teach health education are ongoing in some areas, the full SAFE strategy has not yet been implemented in all endemic areas of Guinea.

Enrollment and Data Collection

Prevalence surveys and the concurrent household sanitation questionnaire were conducted by the Ministry of Health of Guinea, with support from Helen Keller International, in each of the 11 health districts. At least 20 communities were selected from each district by probability proportional to size (PPS) sampling, and in each community the random walk method was used to select households using systematic random sampling. At each household, all individuals were examined for signs of trachoma using the WHO trachoma grading classification system (WHO 1993). Surveys continued in each community until at least 80 children 1-9 years old and 50 women 15 years or older were examined, such that about 20 households were included in the survey of each community.

The household sanitation questionnaire focused on risk factors considered important to trachoma transmission including water source and distance from water, latrine ownership, and latrine cleanliness. At each household an adult member of the household was interviewed and asked to show the surveyors the household latrine if one was present. Surveyors noted by observation whether the latrine was used based on presence of fecal matter in the latrine, and whether it was clean based on whether fecal matter was left outside the pit or if it was otherwise poorly maintained. Urban/rural status was determined by the location of the community: if the community was within a moderately sized or large urban area, such as the capital of the health district, it was classified as "urban", otherwise it was classified as "rural."

The complete data from 2012 and 2013 included 20 communities from the health districts of Beyla, Gaoual, Kankan, Koubia, Koundara, Mali and Tougue; 21 communities from Kerouane; 22 from Siguiri, 23 from Mandiana; and 24 from Yomou. In total 52,293 individuals from 4,858 households in the 230 communities were examined, 22,956 of whom were children between 1 and 9 years old. Analysis for this study was restricted to 1- to 9-year-old children because of the epidemiological and programmatic relevance of this age group in estimating the burden of trachoma (Solomon *et al.* 2006). Only latrine factors from the household survey were considered in this study due to the lack of a clear association between water-access indicators and active trachoma noted in the literature (Stocks *et al.* 2013).

Descriptive Statistics and Unadjusted Analysis

All analyses, including descriptive statistics, bivariate analysis and multivariable analyses were conducted using Stata 9.5. The outcome of interest for bivariate analysis was active trachoma, measured as trachomatous inflammation—follicular and/or trachomatous inflammation—intense (TF/TI) in either eye. For each of the eleven districts, we estimated TF/TI prevalence in 1-9 year-olds, percentage of households with any TF/TI at all in 1-9 year-olds, percent of households using a latrine, and percent of households with a clean latrine (vs. a dirty one or no latrine). Calculations were performed to account for complex survey design.

The primary exposures of interest were three slightly different, but related, dichotomous latrine factors: whether the child's household (a) used a latrine vs. did not use a latrine (n=22,954); (b) used a clean latrine vs. used a dirty one (n=15,087); and (c) used a clean latrine vs. did not use a latrine or used a dirty one (n=22,954). Families without a latrine were included in those "not using" a latrine. Other independent variables considered in bivariate analysis were gender, age, whether the child was in school, urban/rural status, presence of ocular discharge, and presence of nasal discharge.

Bivariate, unadjusted models were developed using generalized linear models with a complex survey design—however, this method did not account for within-district or within-household clustering as in the mixed-effects analysis described below.

Multivariable Analysis: Assessing the impact of household sanitation on active trachoma in 1-9 year-olds

Two multivariable population models were developed using mixed-effects logistic regression to assess the separate effect of latrine use and latrine cleanliness on TF/TI in all 1-9 year-olds in the study. To develop these two models, a backwards elimination approach was used in which all factors described in the bivariate analysis, with the exceptions of ocular and nasal discharge, were included and assessed for their statistical significance to the model in a stepwise fashion. Ocular and nasal discharge were not included in the modeling approach because these discharges are known symptoms of trachoma disease and may also be intermediate causes for the disease (Gower *et al.* 2006; Burton 2007), and as intervening factors they therefore do not meet the a priori criteria for confounders (Kamangar 2012).

This stepwise backwards elimination approach was performed in a pooled model for all eleven districts, and separately for the two dichotomous latrine exposure described above. If a potential confounder was significant to any model at the α=5% level for any district, it was included in the final models for both exposures so as to maintain consistency across the two models. The random effects included in the mixed-effects modeling were the within-district, within-community, and within-household variations, and the intra-class correlations of these effects were estimated for each model.

To investigate variation in the effect of household sanitation on TF/TI in each district, the models were applied separately to each health district and presented as stratified models.

Multivariable Analysis: Assessing the effect of community-level sanitation on community trachoma

Four models were developed using mixed-effects logistic regression to assess the effect of latrine use and cleanliness on TF/TI prevalence within communities. The two outcomes of interest for these models were: whether or not estimated TF/TI prevalence in 1-9 year-olds was above 10%, and whether prevalence was above 5%. These prevalence thresholds are important from a programmatic standpoint: when district prevalence is below 10%, surveys should be conducted at the community level to identify which communities have a prevalence over 5%, and those communities with TF/TI prevalence over 5% are recommended to receive mass antibiotic treatment under current guidelines (Solomon *et al.* 2006). Once a community's TF/TI prevalence is brought below 5% and maintained below this threshold for three consecutive years, it is certified as having eliminated blinding trachoma (Resnikoff *et al.* 2007).

Two models were developed for each of two latrine exposures of interest: percentage of households in a community using a latrine, and percentage using a clean latrine among all households (with or without a latrine). The factors assessed as confounders were the percentage of children in the community attending school, and urban/rural status of the community. A backwards elimination approach was used to assess the importance of these factors. We included a random effect for district variation, and the intra-class correlation was estimated for each model.

Multivariate Analysis: Assessing the linear association between community sanitation and community trachoma

To assess the linear relationship between community latrine use and cleanliness with community trachoma, we first looked at scatter plots, best-fit lines and lowess lines to examine the linear relationship at various levels of community latrine use and cleanliness. From the plots for community latrine use, it was hypothesized that a change in the slope of the line occurred above 50% latrine use community-wide. Similarly, from the plots for community latrine cleanliness, it was also hypothesized that a change in the association occurred above 50% latrine cleanliness.

Six models were then developed using mixed-effects linear regression to assess these linear relationships. The outcome of interest for these models was community TF/TI prevalence. The linear association between community latrine use and cleanliness with community TF/TI prevalence was tested overall, then stratified on community-wide latrine coverage and cleanliness above and below 50%. Urban/rural status and percent of children in the community attending school were assessed as potential confounders. Backwards elimination was used to assess the importance of these factors, and a random effect for within-district variation was included in each model.

Multivariate Analysis: Assessing the combined effects of household and community sanitation on active trachoma in 1-9 year-olds

After developing the two multivariable population models for the impact of household sanitation on active trachoma in children, and after assessing the role of community sanitation on community trachoma prevalence, we extended the population models to assess for the combined effect of household and community sanitation on TF/TI in 1-9 year-olds. In this approach, we used as base models the mixed-effects models previously developed for the impact of household sanitation on TF/TI.

We first assessed the existence of significant interaction between the household and community latrine factors with the percentage of the community (a) using a latrine and (b) with a clean, used latrine as the community factor in each model. If the interaction was not significant at the α=5% level, we removed the term from the model and assessed the significance of the household and community sanitation factors remaining in the reduced model.

We included random effects for the within-household and within-community variation. Since these combined-effect models would not converge when including a random effect for within-district variation, a variance estimate was included to allow for intra-district correlation.

Ethical Considerations

This study was deemed exempt from ethics approval by the Emory University Institutional Review Board, since the data were previously collected and analyzed for internal use by the Ministry of Health of Guinea, and thus did not qualify as human subjects research. The data were de-identified for this secondary analysis.

Results

Characteristics of Population And Households

The estimated characteristics of the 1-9 year-old population and the households from the 11 health districts are shown in Table 1. The Yomou health district had the lowest prevalence, with 1.0% (95%CI 0.5 - 1.8%) of 1-9 year-olds showing TF/TI, while the highest prevalence of 25.1% (95%CI 22.6 - 27.9%) was seen in the Kankan health district. Kankan, Kerouane, Mandiana, and Siguiri had the four highest prevalences of TF/TI despite having the highest household latrine use. Latrine cleanliness, however, differed greatly from use by district, and these four areas all border each other geographically, are ethnically similar, and share very similar environmental conditions, all of which may have an important unmeasured impact on trachoma prevalence.

Bivariate Associations of Potential Risk Factors with Active Trachoma

Crude associations between covariates and TF/TI, unadjusted for clustering, are shown in Table 2. The overall prevalence of TF/TI in 1-9 year-olds in these eleven districts was 8.9% (95%CI 8.1 - 9.7%). Girls and boys were equally likely to present with TF or TI (PR 0.97, 95%CI 0.88 - 1.07), and 5-year-olds showed the highest prevalence of disease. Children who were enrolled in school were less likely to have TF/TI (PR 0.67, 95%CI 0.55 - 0.82), as were children living in urban areas (PR 0.57, 95%CI 0.38 - 0.86). Ocular and nasal discharge were both positively associated with TF/TI. Overall, latrine use and cleanliness were inconclusive with regard to TF/TI: children in households using latrines seemed to have higher TF/TI, while having a clean latrine appeared either protective or to have no effect on TF/TI in 1-9 year-olds.

Association between Latrines and Active Trachoma in 1-9 Year-Olds

The mixed-effects logistic models for effect of the latrine factors on population TF/TI and the intra-class correlations for within-community and within-household effects are shown in Table 3. Overall, household use of a latrine had no effect on TF/TI in 1-9 year-olds, while latrine cleanliness had a protective effect (POR 0.69, 95%CI 0.60 - 0.80). This association varied greatly by district, as shown in the district-stratified models presented in the supplementary material, such that latrine use was significantly protective in Tougue, while in other districts latrine cleanliness showed no statistically significant effect on TF/TI. Urban/rural status and number of 1-9 year-old children per household were found to be associated with active trachoma in 1-9 year-olds in the reduced and adjusted models.

In the overall models, the intra-class correlations were highest within households. In the model for latrine use 13% of the ICC was within households (overall ICC 0.33, 95%CI 0.29 – 0.36), and in the model for latrine cleanliness 12% of the ICC was within households (overall ICC 0.27, 95%CI 0.24 – 0.31)

In the district-stratified models shown in the supplemental material (A), the within-community correlation of TF/TI with regard to the factors in the models was low, ranging from 0% to 19% correlation within communities, while the within-household correlation was quite high in some districts but not in others, ranging from 0% to 40% at the household level. Notably, in the districts with lower TF/TI prevalence, ICCs were quite high within households but not within communities. This observations indicates that—especially in districts of low prevalence—trachoma is highly clustered within households.

Association between Latrine Coverage and Community TF/TI Prevalence

The mixed-effects logistic models for the influence of community latrine use and cleanliness on community TF/TI prevalence are shown in Table 4. Latrine use and cleanliness had no statistically significant influence on whether or not a community had a TF/TI prevalence above 10% in 1-9 year-olds, while urban/rural status had a significant effect for these models, such that urban communities were 14 times less likely to have a TF/TI prevalence over 10% than rural communities when latrine use was the exposure of interest (POR 0.06, 95%CI 0.01 – 0.27) and 17 times more likely when latrine cleanliness was the exposure (POR 0.07, 95%CI 0.01 – 0.34). The interaction between urban status and the latrine factors was not statistically significant in any of these models, and was therefore not included in the final models.

The effect of urban/rural status was non-significant when considering whether or not a community had a TF/TI prevalence above 5% in 1-9 year-olds, rather than above 10%. Both latrine use and latrine cleanliness were significantly protective when considering the 5%

prevalence threshold: with an increase in latrine use of 1% in a community, the prevalence-odds ratio for having TF/TI prevalence above 5% (in 1-9 year-olds) was reduced by 0.98 times (95%CI 0.96 - 0.99), such that a 10% increase in latrine use community-wide might be expected to lead to 0.79 (95%CI 0.67 - 0.92) times the odds of having prevalence over 5%—a 1.27-times reduction in the odds of TF/TI. The effect was similar for percent of households with clean latrines (POR 0.96, 95%CI 0.94 - 0.98).

Intra-cluster correlations at the district level were above 0.70 in all four of these models, indicating that districts were quite homogenous in terms of TF/TI prevalence such that communities with a prevalence under 5% and 10% tended to be in the same districts as other communities with a prevalence under 5% and 10%, and districts where communities had higher prevalence were similarly homogenous.

Linear Association between Sanitation and Trachoma Prevalence at the Community-level

The linear associations between community latrine use and cleanliness and community TF/TI prevalence are shown in Table 5. In communities where latrine use was 50% or lower, increased latrine use was significantly associated with decreased TF/TI prevalence, but in communities with over 50% latrine use, further increases in latrine use had no effect on TF/TI prevalence. Overall, increased use was statistically associated with decreased TF/TI prevalence (β=-0.03, p=0.014), such that a 20% increase in latrine use community-wide would only be expected to lower TF/TI prevalence by about 0.6%. Though this slope is statistically significant, its small value is not practically meaningful. Urban status was strongly associated with decreased TF/TI prevalence in all models except the model assessing the effect of 50% or lower latrine use.

In all three models for community latrine cleanliness, increased cleanliness was significantly associated with decreased TF/TI. Interestingly, the greatest effect of increased latrine cleanliness was seen in communities where over 50% of households had clean latrines (β=0.20, p=0.001), such that a 20% increase in latrine cleanliness above 50% community-wide would be expected to lower TF/TI prevalence by about 4%. These results indicate that while increases in latrine cleanliness may not have a large effect on TF/TI prevalence in areas with low latrine coverage, the cleanliness of latrines becomes increasingly important as sanitation increases community-wide.

Intra-district correlations were quite high in these models as well, as in the logistic models described above. This observation reiterates the existence of high homogeneity of disease within districts.

Combined Impact of Household and Community Sanitation on Active Trachoma in 1-9 Year-Olds

When community sanitation factors were added to the base models for TF/TI, only the model for latrine cleanliness had significant community sanitation factors (Table 5). There was significant interaction between community latrine cleanliness and household latrine cleanliness (POR 0.99, 95% CI 0.98 – 0.99). However, when this interaction term was included in the model, the terms for household latrine cleanliness and community latrine cleanliness were not significant. According to this model, even a 100% increase in community latrine cleanliness would not lead to a statistically significant change in TF/TI risk even in households using a clean latrine (POR 0.83, 95% CI 0.25 – 2.75).

The interaction between household and community latrine cleanliness was not significant, nor was the term for community latrine cleanliness when the interaction term was removed from the model. This finding reflects the results of the earlier population models that showed no effect of latrine use on TF/TI in 1-9 year-olds. Because these models showed no significant association with community latrine use, nor its interaction with household latrine use, they are not reported here. In our model selection for these models, we considered stratifying the models above and below 50% use and cleanliness, in concordance with the previous finding that the association between latrine factors and trachoma changed at about 50% coverage, but the results produced by stratification were no more meaningful than those shown in the model in Table 6.

Discussion

Our data reveal that although the use of household latrines appears to have no association with active trachoma, latrine cleanliness is associated with lower TF/TI in children, such that children in households with a clean latrine are about a third less likely to have TF/TI. Urban status was also associated with lower TF/TI, and the number of children in a household was positively associated with TF/TI. At the community level, both overall latrine use and latrine cleanliness were associated with lower TF/TI prevalence, and especially with reduction of prevalence to below the 5% threshold. The combined effect of household latrine factors and community latrine coverage is somewhat elusive, but we showed that the interaction of these factors is significant with regard to latrine cleanliness. The results of this study also demonstrate that trachoma is highly clustered within households and within geographic areas—in this case health districts.

The clustering of active trachoma in households was highest in the health districts with the lowest prevalence of disease. This supports the earlier evidence that trachoma is highly clustered in households (Burton 2007; Mabey *et al* 1992; Katz *et al* 1988; Tielsch *et al* 1988), and emphasizes the role that households play in maintaining trachoma, especially at low prevalence. Within-district clustering is high, which indicates that while trachoma burden may vary greatly within a given country, as demonstrated by the wide range of prevalence in these 11 health districts, it is quite homogenous within these smaller geographic areas.

Our finding that household latrine cleanliness was protective of TF/TI, but that mere latrine use had no apparent effect adds an important element to the discussion of the role of sanitation in the fight against trachoma. Most studies on the effect of household sanitation on trachoma have demonstrated, as this study has, that while household latrines seem to be protective of trachoma, this effect is rarely found to be statistically significant (Stocks *et al* 2013; Rabiu *et al* 2012). We have demonstrated that use of a *clean* household latrine has a clear, statistically significant association with lower TF/TI in 1-9 year-olds, and therefore it seems that the cleanliness of these facilities may be the true driver of trachoma reduction through sanitation. This finding is sensible from a biological standpoint, since flies would be less likely to breed in latrines that are covered, well-maintained, and clean (Galal *et al.* 2001).

At the community level, both latrine use and latrine cleanliness were associated with trachoma prevalence below 5%--but not below 10%. This finding indicates that at very low prevalence, household latrines play a role in keeping trachoma burden low, and adds to the body of evidence that associates reduced trachoma prevalence with higher sanitation infrastructure (Courtright *et al* 1991; Tielsch *et al* 1988; Zerihoun *et al* 997; Emerson *et al* 2004; Golovoty *et al* 2004). From a programmatic standpoint this is acutely important since communities are only considered as having eliminated blinding trachoma when TF/TI prevalence in 1-9 year-olds has been kept below 5% for three consecutive years (Resnikoff *et al* 2007), and suggests that latrines will play a very important part in keeping trachoma prevalence below this threshold after communities have achieved elimination.

Our assessment of the linear relationship between sanitation and community TF/TI prevalence showed that although increases in latrine use community-wide were associated with statistically significant decreases in TF/TI prevalence, the effect was not meaningful, such that below 50% latrine use, a 10% increase in use would only result in about a 0.7% decrease in prevalence (β=-0.07, p=0.001). The effect below 50% latrine cleanliness was similarly negligible (β=-0.06, p=0.019), but above 50% latrine cleanliness, increases in community-wide latrine cleanliness were significant and somewhat meaningful, such that a 10% increase in latrine cleanliness should lead to a 2% decrease in TF/TI prevalence (β=-0.20, p=0.001). This finding has important implications for trachoma control as well: it suggests that the payoff expected from increased latrine use and cleanliness, in terms of reduction in trachoma prevalence, will not likely be recognized until latrine use and cleanliness are at high levels community-wide.

Although, as noted above, the combined effects of household latrine factors and community latrine factors did not show empirically meaningful results, this study revealed that both household and community latrine factors had an important impact on active trachoma in children. The methods that assessed these factors separately showed household latrine cleanliness, and community latrine use and cleanliness to be significantly and meaningfully associated with reduced active trachoma. Our analysis failed to elucidate the combined effect of household and community sanitation, but the evidence presented here suggests that a combined effect exists. Because household and community latrine factors are so inherently related, it will be difficult to determine empirically how much influence each of these mixed-level factors has on TF/TI risk. Further study is needed to elucidate whether simply having a clean household latrine is protective of trachoma or if this effect is modified by community latrine coverage and cleanliness.

Policy Implications

Due to the evidence of an association between latrine cleanliness and reduction of active trachoma risk, it is strongly recommended that the importance of maintaining a clean latrine be worked into the “environmental change” element of the SAFE strategy. As this study and others have shown, it is not enough to merely construct latrines if people are not taught to maintain and use them properly (Rotondo 2009; Ngondi 2010).

The observation that latrine use and cleanliness do not have a recognizable effect on the prevalence of TF/TI until prevalence is below 5% is also important to the overall SAFE strategy.

As trachoma-affected countries grapple with addressing the disease burden, they are seeking effective means to reduce prevalence below the elimination threshold of 5%. Latrine use and cleanliness are clearly part of the answer. Both building latrines and teaching people to keep them clean should be a priority of all countries' strategy to eliminate blinding trachoma.

The observation that reduction of TF/TI prevalence in communities only becomes significant and meaningful when latrine cleanliness is above 50% indicates the existence of a threshold of coverage that must be attained to observe reduction of community trachoma burden. However, our choice to split the data at this 50% coverage level was based on our observation of weighted scatter plots and lines which did not take into account the important effect of within-district clustering. The reduction of prevalence beyond this artificial threshold should be taken as evidence for a meaningful effect at high latrine coverage, but much further study is needed to confirm its existence and quantify exactly what this threshold is. Some documents for trachoma control have suggested ultimate intervention goals for latrine coverage of 80-85% (WHO 2010; Solomon 2006), but these percentages are not based on empirical evidence. Identifying such a threshold would be very important for countries planning their ultimate intervention goals for the E element of the SAFE strategy.

The evidence shown here is clear: latrines do have a measureable and significant association with reduced trachoma. This evidence should serve to rally stakeholders to invest in sanitation infrastructure to achieve high coverage and cleanliness of latrines in countries burdened with trachoma.

Strengths and Limitations

The complete etiology of trachoma is complicated and, even after many studies on root causes and effective interventions, still poorly understood in some aspects; factors that contribute to trachoma disease may also vary considerably by region, climate, and behavioral factors (Hu *et* *al* 2010; Emerson *et al* 2000). Unfortunately, many of these factors were not measured in our study, so we could not assess or control for their effects in our analysis. Unmeasured factors likely account for a great deal of the variation in TF/TI and latrine factors in Guinea, such as facial hygiene and the fact that the health districts in our study with the highest latrine coverage—Kankan, Siguiri, and Mandiana—have, paradoxically, the highest burden of trachoma.

Our survey was also vulnerable to some bias due to measurement error from the health workers who conducted the surveys, especially with regard to latrine cleanliness, which was a fairly subjective dichotomous measure that was judged by the surveyors. Still, surveyors were trained to identify clean latrines based on clear criteria such as presence of fecal matter outside the latrine pit and flies in the latrine. Regardless, this potential bias would be expected to be non-differential, since surveyors would judge all latrines by the same criteria regardless of whether children in the household had active trachoma. Therefore, if a bias existed on this cleanliness variable, it would logically bias the estimate toward the null value, and so the effect of latrine cleanliness could actually be associated with lower disease than demonstrated here.

The use of TF/TI as an indicator of trachoma is common in research and among trachoma control programs, but it is not as good an indicator of trachoma burden as lab-verified infection with PCR (Taylor 2003). The use of this indicator in our study thus opens up our study to bias, since children may be infected with trachoma, but the infection has not yet developed into TF. Therefore it is likely that our study underestimates the true effects of latrine use and cleanliness on trachoma infection.

We noted a great deal of clustering of disease within households, with little clustering between households in the same district. However, due to blinding and our survey methodology, we could not assess whether trachoma was clustered among neighbors or households that were geographically close to one another. Also, since the districts in our study were chosen for programmatic reasons and not by random selection, we could not draw conclusions about trachoma or latrines in Guinea country-wide.

Despite these limitations our study had a number of strengths. The random community and household sampling within districts allowed us to make sound inferences on a large scale, especially with regard to clustering of the disease at many levels, and the fact that about 2,000 children were sampled from each of the 11 districts lends high validity to our study. The mixed-effects modeling approach also ensured greater validity in our results by taking into account the large variations within households, communities and districts.

Although the districts in this study were not selected randomly, they do represent much of the regional diversity of Guinea: districts from the upper, middle, and forest regions of the country are all included. In further study in Guinea, it may be worthwhile to compare the burden of disease and sanitation coverage between all ecological regions of the country. Few studies on the effects of latrines on trachoma have had as large a scope as this one, in which a third of the health districts of the entire country were studied, and the sample is very large and representative for each respective district.

Recommendations

Our study highlights the need for greater sanitation infrastructure to address the problem of trachoma. We have shown that latrine cleanliness is significantly associated with reduced risk of trachoma, and thus it is necessary to invest in sanitation infrastructure, to teach good environmental hygiene, and to direct it especially towards individuals in a position to teach good hygiene and sanitation habits to children from an early age, such as mothers and girls. Full implementation of the SAFE strategy is required not only to eliminate blinding trachoma, but to keep the burden of disease low after it has been reduced below endemic levels. We must invest in infrastructure in all communities—not simply in urban centers or easily accessible areas—since areas that lack resources and have been traditionally neglected will be the areas that continue to harbor disease long after disease burden has been reduced on larger scales.

This study also highlights many areas where further research into etiologies of trachoma and effective interventions are needed. Environmental and climate factors are likely to be very important to trachoma disease and persistence of *C. trachomatis* in the environment, as are seasonal differences in access to water and, consequently, hygiene. The importance of geographic clustering of disease among neighbors is not well understood, nor are the effects of other water and sanitation factors. It would be particularly useful to study the reduction of trachoma in Guinea after several years of the SAFE strategy, since surgery and mass distribution of antibiotics have been ongoing in several health districts in the time since completing these surveys.

If fully implemented in all communities where trachoma is a problem, the full SAFE strategy is bound to be effective in reducing the burden of disease, whether the aforementioned factors are fully understood or not. We therefore encourage not just further research into the root causes and effective interventions for this disease, but greater investment in resources and infrastructure to fully implement the SAFE strategy and achieve the goal of elimination of blinding trachoma by 2020.

Finally, we are pleased to present the results of this study because few studies on trachoma have been done in Guinea, and this work helps to shed light on the burden of the disease in the country and some of the disparities in infrastructure here, which has an impact on health and quality of life far beyond trachoma disease. We hope that this work will attract investment in the people and infrastructure of Guinea to improve health and provide greater opportunity to its residents.

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Table 1. Characteristics of 1-9 year-old sample population and households in 11 health districts in Guinea, 2012 and 2013

Health District	TF/TI Prevalence		Households using a latrine		Households with a clean latrine*	
	n	No. positive in sample (%)	n	Frequency in sample	n	Frequency in sample
Beyla	1,939	47 (2.4)	393	251 (63.9)	393	105 (26.7)
Gaoual	1,924	64 (3.3)	479	299 (62.4)	479	135 (28.2)
Kankan	2,176	547 (25.1)	423	406 (96.0)	423	170 (40.2)
Kerouane	2,015	215 (10.7)	421	377 (89.5)	421	274 (65.1)
Koubia	1,739	36 (2.1)	409	198 (48.4)	409	154 (37.7)
Koundara	2,022	173 (8.6)	459	242 (52.7)	459	209 (45.5)
Mali	2,336	124 (5.3)	441	76 (17.2)	441	58 (13.2)
Mandiana	2,329	349 (15.0)	450	387 (86.0)	450	156 (34.7)
Siguiri	2,429	402 (16.6)	441	401 (90.9)	441	106 (24.0)
Tougue	2,057	66 (3.2)	409	286 (69.9)	409	119 (29.1)
Yomou	1,988	19 (1.0)	442	137 (31.0)	442	37 (8.4)

*As opposed to a dirty latrine or no latrine use.

Table 2. Prevalence of active trachoma and potential risk factors in 11 health districts in Guinea in 2012 and 2013*

		n	No. positive	TF/TI Prevalence (%) (95% CI)		Prevalence Ratio (95% CI)	
TF or TI		22,954	2042	8.9	(8.1 - 9.7)	n/a	
Sex	Male	11,443	1,003	8.8	(7.9 - 9.7)	0.97	(0.88 - 1.07)
	Female	11,490	1,038	9.0	(8.2 - 10.0)		Reference
Age	1	2,188	83	3.8	(2.9 - 5.0)	0.31	(0.16 - 0.59)
	2	2,359	211	8.9	(7.5 - 10.6)	0.72	(0.52 - 1.00)
	3	2,622	279	10.6	(9.2 - 12.3)	0.86	(0.70 - 1.05)
	4	2,470	252	10.2	(9.0 - 11.6)	0.82	(0.65 - 1.03)
	5	2,425	301	12.4	(10.8 - 14.2)		Reference
	6	2,437	254	10.4	(9.0 - 12.1)	0.84	(0.72 - 0.98)
	7	2,766	201	7.3	(6.2 - 8.5)	0.59	(0.50 - 0.69)
	8	2,431	214	8.8	(7.5 - 10.3)	0.71	(0.60 - 0.84)
	9	3,256	247	7.6	(6.3 - 9.1)	0.61	(0.48 - 0.78)
Enrolled in school	Yes	3,938	250	6.3	(5.2 - 7.8)	0.67	(0.55 - 0.82)
	No	19,016	1792	9.4	(8.6 - 10.3)		Reference
Urban status	Urban	3,335	180	5.4	(**)	0.57	(0.38 - 0.86)
	Rural	19,619	1,862	9.5	(8.7 - 10.3)		Reference
Ocular discharge	Yes	1,687	476	28.2	(23.4 - 33.5)	3.83	(3.11 - 4.73)
	No	21,266	1,565	7.4	(6.6 - 8.1)		Reference
Nasal discharge	Yes	3,490	476	13.6	(11.9 - 15.5)	1.70	(1.49 - 1.93)
	No	19,464	1,566	8.0	(7.3 - 8.8)		Reference
Household uses latrine	Yes	15,087	1,600	10.6	(9.6 - 11.7)	1.89	(1.57 - 2.28)
	No	7,867	442	5.6	(4.8 - 6.6)		Reference
Clean vs. dirty or no latrine	Clean	7,329	600	8.2	(7.0 - 9.6)	0.89	(0.73 - 1.08)
	Dirty or no latrine	15,625	1,442	9.2	(8.3 - 10.2)		Reference
Clean vs. dirty latrine	Clean	7,329	600	8.2	(7.0 - 9.6)	0.64	(0.52 - 0.78)
	Dirty	7,758	1,000	12.9	(11.4 - 14.6)		Reference

*Bivariate analysis did not account for within-household clustering.

**95% CI for urban prevalence could not be calculated because one district did not include an urban community in the random sample.

Table 3. Multivariate mixed-effects models for the effect of household latrine use and cleanliness on TF/TI in 1-9 year-olds in 11 health districts in Guinea in 2012 and 2013

	Fixed Effects	*POR (95% CI)*	*P-value*
Latrine use	Latrine use	0.87 (0.73 - 1.05)	0.151
	Urban status	**0.55 (0.38 - 0.81)**	**0.002**
	No. of children	**1.06 (1.03 - 1.08)**	**<0.001**
	$\rho_{district}$	0.13 (0.11 - 0.15)	
	→ $\rho_{community}$	0.20 (0.17 - 0.24)	
	→ $\rho_{household}$	0.33 (0.29 - 0.36)	
	Fixed Effects	*POR (95% CI)*	*P-value*
Latrine cleanliness	Clean latrine*	**0.69 (0.60 - 0.80)**	**<0.001**
	Urban status	**0.63 (0.46 - 0.85)**	**0.003**
	No. of children	**1.05 (1.03 - 1.08)**	**<0.001**
	$\rho_{District}$	0.07 (0.06 - 0.09)	
	→ $\rho_{Community}$	0.15 (0.12 - 0.18)	
	→ $\rho_{Household}$	0.27 (0.24 - 0.31)	

Table 4. Multivariate mixed-effects model for the effect of community latrine use and cleanliness on TF/TI prevalence over 10% and over 5% in 1-9 year-old children in 11 health districts in Guinea in 2012 and 2013

		Effect on prevalence over 10%		**Effect on prevalence over 5%**	
	Fixed Effects	*POR (95% CI)*	*P-value*	*POR (95% CI)*	*P-value*
Latrine use	Percent of households **using a latrine** (continuous)	0.98 (0.96 - 1.00)	0.072	**0.98 (0.96 - 0.99)**	**0.003**
	Urban status	**0.06 (0.01 - 0.27)**	**<0.001**	0.45 (0.15 - 1.33)	0.148
	$\rho_{district}$	0.81 (0.53 - 0.94)		0.76 (0.51 - 0.91)	
	Fixed Effects	*POR (95% CI)*	*P-value*	*POR (95% CI)*	*P-value*
Latrine cleanliness	Percent of households with a **clean latrine** (continuous)	0.98 (0.96 - 1.00)	0.082	**0.96 (0.94 - 0.98)**	**0.001**
	Urban status	**0.07 (0.01 - 0.34)**	**0.001**	0.48 (0.16 - 1.43)	0.189
	$\rho_{district}$	0.78 (0.49 - 0.92)		0.77 (0.51 - 0.92)	

Table 5. Multivariate mixed-effects model for the linear association of community latrine use and cleanliness with TF/TI prevalence in 1-9 year-old children in 11 health districts in Guinea in 2012 and 2013

	50% or less latrine use (n=79)		**Over 50% latrine use (n=151)**		**Overall latrine use (n=230)**	
Fixed Effects	*Coefficient (SE)*	*P-value*	*Coefficient (SE)*	*P-value*	*Coefficient (SE)*	*P-value*
Percent of households **using a latrine** (continuous)	**-0.07 (0.02)**	**0.001**	-0.05 (0.04)	0.165	**-0.03 (0.01)**	**0.014**
Urban status	-0.83 (0.85)	0.327	**-6.32 (1.40)**	**<0.001**	**-4.00 (0.95)**	**<0.001**
$\rho_{district}$	0.44 (0.17 - 0.75)		0.68 (0.46 - 0.84)		0.72 (0.51 - 0.86)	
	50% or less latrine cleanliness (n=168)		**Over 50% latrine cleanliness (n=62)**		**Overall latrine cleanliness (n=230)**	
Fixed Effects	*Coefficient (SE)*	*P-value*	*Coefficient (SE)*	*P-value*	*Coefficient (SE)*	*P-value*
Percent of households with a **clean latrine*** (continuous)	**-0.06 (0.03)**	**0.019**	**-0.20 (0.06)**	**0.001**	**-0.05 (0.01)**	**<0.001**
Urban status	**-2.59 (1.13)**	**0.022**	**-5.53 (1.90)**	**0.004**	**-3.81 (0.92)**	**<0.001**
$\rho_{district}$	0.75 (0.56 - 0.88)		0.61 (0.34 - 0.82)		0.71 (0.51 - 0.86)	

*As opposed to a dirty latrine or no latrine use.

Table 6. Multivariate model for the interaction of household and community latrine cleanliness and its effect on TF/TI in 1-9 year-olds in 11 health districts in Guinea in 2012 and 2013

	POR or ICC (95% CI)	**P-value**
Clean household latrine*	1.32 (0.76 - 2.29)	0.320
Urban status	0.52 (0.26 - 1.04)	0.065
No. of children	**1.06 (1.00 - 1.12)**	**0.045**
Percent of community with clean latrine (continuous)	1.01 (1.00 - 1.02)	0.218
Interaction: Household & Community latrine cleanliness	**0.99 (0.98 - 0.99)**	**<0.001**

*As opposed to a dirty latrine or no latrine use.

A. Multivariate mixed-effects models for the effect of household latrine use and cleanliness on TF/TI in 1-9 year-olds in 11 health districts in Guinea in 2012 and 2013, stratified by health district

Latrine use			Latrine cleanliness		
Beyla *(TF/TI Prevalence: 2.4%)*					
Fixed Effects	*POR (95% CI)*	*P-value*	*Fixed Effects*	*POR (95% CI)*	*P-value*
Latrine use	0.97 (0.44 - 2.14)	0.947	Clean latrine[1]	1.13 (0.42 - 2.96)	0.818
Urban status	0.44 (0.05 - 3.94)	0.466	Urban status	0.45 (0.05 - 4.10)	0.481
No. of children	0.87 (0.73 - 1.03)	0.104	No. of children	0.87 (0.73 - 1.03)	0.106
$\rho_{community}$	0.18 (0.06 - 0.44)		$\rho_{community}$	0.19 (0.06 - 0.47)	
→ $\rho_{household}$	0.41 (0.22 - 0.63)		→ $\rho_{household}$	0.41 (0.22 - 0.63)	
Gaoual *(TF/TI Prevalence: 3.3%)*					
Fixed Effects	*POR (95% CI)*	*P-value*	*Fixed Effects*	*POR (95% CI)*	*P-value*
Latrine use	0.82 (0.40 - 1.71)	0.601	Clean latrine[1]	0.52 (0.23 - 1.20)	0.124
Urban status	1.12 (0.18 - 7.11)	0.906	Urban status	1.07 (0.18 - 6.51)	0.943
No. of children	0.98 (0.85 - 1.13)	0.759	No. of children	0.97 (0.85 - 1.12)	0.710
$\rho_{community}$	0.10 (0.02 - 0.32)		$\rho_{community}$	0.09 (0.02 - 0.28)	
→ $\rho_{household}$	0.25 (0.11 - 0.47)		→ $\rho_{household}$	0.24 (0.10 - 0.46)	
Kankan *(TF/TI Prevalence: 25.1%)*					
Fixed Effects	*POR (95% CI)*	*P-value*	*Fixed Effects*	*POR (95% CI)*	*P-value*
Latrine use	1.71 (0.80 - 3.70)	0.169	Clean latrine[1]	0.89 (0.70 - 1.14)	0.358
Urban status	0.89 (0.46 - 1.73)	0.736	Urban status	0.94 (0.49 - 1.77)	0.839
No. of children	1.02 (0.98 - 1.07)	0.248	No. of children	1.03 (0.99 - 1.08)	0.182
$\rho_{community}$	0.01 (0.00 - 0.06)		$\rho_{community}$	0.01 (0.00 - 0.07)	
→ $\rho_{household}$	0.08 (0.04 - 0.15)		→ $\rho_{household}$	0.08 (0.04 - 0.15)	
Kerouane *(TF/TI Prevalence: 10.7%)*					
Fixed Effects	*POR (95% CI)*	*P-value*	*Fixed Effects*	*POR (95% CI)*	*P-value*
Latrine use	1.05 (0.66 - 1.69)	0.831	Clean latrine[1]	**0.51 (0.37 - 0.70)**	**<0.001**
Urban status	**0.35 (0.14 - 0.88)**	**0.026**	Urban status	**0.37 (0.15 - 0.87)**	**0.023**
No. of children	1.01 (0.95 - 1.06)	0.853	No. of children	0.99 (0.94 - 1.05)	0.756
$\rho_{community}$	0.19 (0.09 - 0.37)		$\rho_{community}$	0.17 (0.07 - 0.34)	
→ $\rho_{household}$	0.19 (0.09 - 0.37)		→ $\rho_{household}$	0.17 (0.07 - 0.34)	
Koubia *(TF/TI Prevalence: 2.1%)*					
Fixed Effects	*POR (95% CI)*	*P-value*	*Fixed Effects*	*POR (95% CI)*	*P-value*
Latrine use	0.73 (0.27 - 1.98)	0.537	Clean latrine[1]	0.89 (0.29 - 2.81)	0.849
Urban status	1.18 (0.28 - 5.06)	0.820	Urban status	1.24 (0.27 - 5.60)	0.780
No. of children	1.01 (0.80 - 1.28)	0.901	No. of children	1.01 (0.80 - 1.27)	0.933
$\rho_{community}$	0.13 (0.03 - 0.42)		$\rho_{community}$	0.13 (0.03 - 0.42)	
→ $\rho_{household}$	0.52 (0.32 - 0.71)		→ $\rho_{household}$	0.52 (0.32 - 0.72)	

A. Cont.

Latrine use			Latrine cleanliness		
Koundara *(TF/TI Prevalence: 8.6%)*					
Fixed Effects	*POR (95% CI)*	*P-value*	*Fixed Effects*	*POR (95% CI)*	*P-value*
Latrine use	0.78 (0.50 - 1.22)	0.279	Clean latrine[1]	0.79 (0.51 - 1.22)	0.291
Urban status	1.15 (0.58 - 2.26)	0.689	Urban status	1.15 (0.59 - 2.26)	0.675
No. of children	1.03 (0.95 - 1.12)	0.504	No. of children	1.03 (0.94 - 1.12)	0.533
$\rho_{community}$	0.05 (0.02 - 0.15)		$\rho_{community}$	0.05 (0.02 - 0.14)	
→ $\rho_{household}$	0.17 (0.08 - 0.31)		→ $\rho_{household}$	0.17 (0.08 - 0.31)	
Mali *(TF/TI Prevalence: 5.3%)*					
Fixed Effects	*POR (95% CI)*	*P-value*	*Fixed Effects*	*POR (95% CI)*	*P-value*
Latrine use	0.62 (0.34 - 1.15)	0.128	Clean latrine[1]	**0.45 (0.20 - 0.99)**	**0.046**
Urban status	1.05 (0.60 - 1.86)	0.863	Urban status	1.04 (0.60 - 1.83)	0.882
No. of children	0.99 (0.92 - 1.06)	0.764	No. of children	0.99 (0.92 - 1.06)	0.722
$\rho_{community}$	0.00 (0.00 - 0.99)		$\rho_{community}$	0.00 (0.00 - 1.00)	
→ $\rho_{household}$	0.00 (0.00 - 0.99)		→ $\rho_{household}$	0.00 (0.00 - 1.00)	
Mandiana *(TF/TI Prevalence: 15.0%)*					
Fixed Effects	*POR (95% CI)*	*P-value*	*Fixed Effects*	*POR (95% CI)*	*P-value*
Latrine use	0.61 (0.33 - 1.13)	0.119	Clean latrine[1]	**0.29 (0.18 - 0.50)**	**<0.001**
Urban status	**0.07 (0.02 - 0.20)**	**<0.001**	Urban status	**0.08 (0.03 - 0.24)**	**<0.001**
No. of children	**1.28 (1.16 - 1.42)**	**<0.001**	No. of children	**1.29 (1.17 - 1.42)**	**<0.001**
$\rho_{community}$	0.02 (0.00 - 0.20)		$\rho_{community}$	0.04 (0.01 - 0.16)	
→ $\rho_{household}$	0.43 (0.33 - 0.53)		→ $\rho_{household}$	0.40 (0.30 - 0.50)	
Siguiri *(TF/TI Prevalence: 16.6%)*					
Fixed Effects	*POR (95% CI)*	*P-value*	*Fixed Effects*	*POR (95% CI)*	*P-value*
Latrine use	1.42 (0.80 - 2.53)	0.230	Clean latrine[1]	1.32 (0.95 - 1.83)	0.096
Urban status	**0.41 (0.23 - 0.75)**	**0.004**	Urban status	**0.39 (0.21 - 0.73)**	**0.003**
No. of children	**1.09 (1.03 - 1.16)**	**0.005**	No. of children	**1.09 (1.03 - 1.16)**	**0.004**
$\rho_{community}$	0.03 (0.01 - 0.08)		$\rho_{community}$	0.03 (0.01 - 0.09)	
→ $\rho_{household}$	0.13 (0.07 - 0.21)		→ $\rho_{household}$	0.13 (0.07 - 0.21)	
Tougue *(TF/TI Prevalence: 3.2%)*					
Fixed Effects	*POR (95% CI)*	*P-value*	*Fixed Effects*	*POR (95% CI)*	*P-value*
Latrine use	**0.41 (0.21 - 0.80)**	**0.010**	Clean latrine[1]	0.56 (0.24 - 1.30)	0.175
Urban status	**		Urban status	**	
No. of children	1.09 (0.99 - 1.19)	0.079	No. of children	1.09 (0.99 - 1.19)	0.072
$\rho_{community}$	0.05 (0.01 - 0.26)		$\rho_{community}$	0.07 (0.02 - 0.25)	
→ $\rho_{household}$	0.24 (0.09 - 0.48)		→ $\rho_{household}$	0.26 (0.12 - 0.49)	

A. Cont.

Latrine use			Latrine cleanliness		
Yomou *(TF/TI Prevalence: 1.0%)*					
Fixed Effects	*POR (95% CI)*	*P-value*	*Fixed Effects*	*POR (95% CI)*	*P-value*
Latrine use	0.63 (0.17 - 2.35)	0.490	Clean latrine[1]	‡	
Urban status	2.25 (0.56 - 9.16)	0.255	Urban status	2.09 (0.50 - 8.74)	0.310
No. of children	1.03 (0.82 - 1.27)	0.840	No. of children	1.01 (0.82 - 1.25)	0.924
$\rho_{community}$	0.06 (0.00 - 0.66)		$\rho_{community}$	0.09 (0.01 - 0.59)	
→ $\rho_{household}$	0.46 (0.17 - 0.77)		→ $\rho_{household}$	0.45 (0.16 - 0.77)	

**Due to random sampling of communities, no urban communities were sampled from Tougue

‡Undefined due to no TF/TI cases with a clean household latrine in Yomou

[1]As opposed to a dirty latrine or no latrine use.