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The independent effects of maternal education and household wealth on malaria risk in children

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Contents

Abstract

Despite evidence that they play similar but independent roles, maternal education and household wealth are usually conflated in studies of the effects of socioeconomic status (SES) on malaria risk. We use Demographic and Health Survey (DHS) and Malaria Indicator Survey (MIS) data from eight countries in sub-Saharan Africa to explore the relationship of malaria parasitemia in children with SES factors, accounting for urban/rural residence and other important covariates. In multilevel logistic regression modeling, completion of six years of maternal schooling was associated with lower odds of infection in children in rural (OR = 0.86) and urban (OR = 0.74) areas, as was a household wealth index at the 40th percentile compared to the lowest percentile ($OR_{RURAL} = 0.68$; $OR_{URBAN} = 0.45$). These relationships were non-linear with respect to the logit of parasitemia, incorporating significant quadratic terms for both education and wealth. Urban residence was associated with a large reduction in risk (OR = 0.43). Among other covariates, increasing child's age was strongly related to infection, and sleeping under an insecticide-treated bednet the previous night or living in high-quality housing were each associated with moderate reductions ($OR_{ITN} = 0.80$; $OR_{HOUS} = 0.85$). Considerable variation in parameter estimates was observed among country-specific models. Future work should clearly distinguish between maternal education and household resources in assessing malaria risk, and policy related to malaria prevention and control should be aware of the potential benefits of supporting the development of human capital.

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About the Author

José Siri was an IIASA Postdoctoral Scholar with the Health and Global Change (HGC) project between July 2009 and June 2011 and subsequently a Research Scholar with the World Population (POP) and Mitigation of Air Pollution and Greenhouse Gases (MAG) programs through October 2012. He received a PhD in epidemiology and MPH in international health from the University of Michigan.

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1 Introduction

A priori expectations and empirical evidence suggest that maternal education affects child health independently of household resources. Yet most studies of the influence of socioeconomic risk factors on health – whether assessing broad indicators like mortality or disease-specific outcomes – equate the effects of wealth and education on risk, blurring the distinction between them. This distinction is of critical importance in designing effective and cost-efficient health and development policy, particularly for resource-poor nations of the developing world. Additionally – and not well appreciated – it is essential to accurately forecasting the long-run evolution of the burden of disease.

This study uses Demographic and Health Survey (DHS) data to address this issue for malaria occurrence in children. In particular, we assess the association of socioeconomic status (SES) variables with confirmed malaria parasitemia, using data from Malaria Indicator Surveys (MIS) and traditional DHS surveys. The addition of parasitological information to the suite of data collected by DHS offers significant opportunities for improving our understanding of how SES affects malaria risk. The main emphasis of this study is on evaluating the independent associations of household wealth and maternal schooling with malaria in children, particularly in the context of urban versus rural residence. Among these variables of primary interest, the relationships among poverty, urban residence and malaria risk have more often been analyzed than the effects of education. Moreover, the link whereby malaria affects school attendance and educational attainment has been examined in greater depth than the complementary relationship – i.e., the effect of maternal education on malaria risk. This study thus provides novel insight into an area of considerable importance.

Since the turn of the millennium, and increasingly since the call to action by the Bill and Melinda Gates Foundation in 2007 (Gates Foundation 2007), a concerted global effort against malaria has achieved major successes, supported by increased funding and ever more sophisticated understandings of the dynamics and operational challenges of malaria control. The scale-up of malaria prevention activities has been responsible for over 0.8 million deaths averted in children since 2000 (Eisele et al. 2012). These triumphs have led to loftier goals; e.g., the prevention of all malaria deaths by 2015, progressive regional elimination and eventually, global eradication (WHO 2011). Yet, while elimination and eradication have emerged firmly back into the global scientific and policy discourse (D’Souza and Newman 2012; Das and Horton 2010; Feachem and Sabot 2008; Feachem et al. 2009; Marsh 2010; Mendis et al. 2009; Moonen et al. 2010; Pindolia et al. 2012; Tanner and De Savigny 2008), technical feasibility studies conclude that we are unlikely to eliminate malaria in high-transmission areas with current capabilities (WHO 2008). Without sustained or increased efforts and funding, regional and global coordination and an array of novel control tools, malaria is likely to remain viable in areas with high intrinsic transmission rates, particularly in sub-Saharan Africa. In fact, despite the recent significant advances, malaria remains one of the most important communicable diseases in the world, causing two-thirds of a million deaths and well over 200 million acute infections in 2010, mostly (80-90%) in sub-Saharan Africa (WHO 2011). International funding for malaria control appears to have peaked in 2010 at ~$2 billion of the estimated $5-6 billion *per annum* needed for elimination (WHO 2011); though much progress has been made, current funding is inadequate for comprehensive malaria control at a global scale (Snow et al. 2010). The recent global financial crisis and competing demands on international financial aid make it doubtful that needed investments will occur or be sustained over the long term. The history of malaria control, of course, is one of significant achievements followed rapidly by resurgence of disease in areas lacking necessary elements of integrated public health infrastructure, when economic and financial crises or waning of political will have contributed to large-scale reductions in funding for prevention and control (Nájera et al. 2011).

In this context, it is critical to find and make efficient use of all effective routes for malaria prevention and containment. Malaria control “toolboxes” typically include interventions that directly affect the dynamics of malaria transmission and progression: case management, larval control, insecticide residual spraying (IRS), insecticide-treated bednets (ITNs), intermittent preventive treatment in pregnant women (IPTp), and chemoprophylaxis in travelers or other at-risk groups (Morel et al. 2005). Other interventions, including vaccines (Schwartz et al. 2012) and vector sterilization (Townson 2009), which are on the horizon but not yet available for wide-scale public health action, also directly affect transmission. In contrast, where SES factors impinge on risk, they generally act at a remove, through their effects on other proximal determinants of risk, and questions of causality arise. Moreover, efforts to, say, improve education or decrease poverty are not malaria-specific, require a much broader set of investments than traditional interventions, and often generate more controversy as well. Yet to the extent that these factors play a causal role in determining risk, the potential of such efforts to constitute important formal components of larger-scale policy for malaria control should be considered in greater detail.

The relationship between SES and malaria has received considerable attention. There is no question that SES factors are correlated with malaria risk. Higher standards of living, for example, were instrumental in the large-scale reductions in malaria in North America and Europe during the late 19th and early 20th centuries (Humphreys 2001). Today, the poorest populations worldwide bear a disproportionate amount of malaria cases and deaths (Barat et al. 2004). However, causality in the relationship between SES factors and malaria is likely bidirectional – for example, it is probable that malaria causes poverty and vice versa, in reinforcing feedback cycles, at the individual, community and potentially national or regional scales (Somi et al. 2007; Teklehaimanot and Mejia 2008).

On the one hand, then, researchers have examined how malaria affects SES factors. At the national level, a widely-cited set of studies have associated malaria endemicity with substantially slower economic growth and decreased per capita GDP (Gallup and Sachs 2001; Sachs and Malaney 2002), although some have questioned whether these results truly demonstrate a causal relationship, citing the inadequacy of data, the complexity of the interrelationships among social and economic factors and health, and the difficulty of extrapolating micro-level data to the macro level (Packard 2009). At the household and individual levels, malaria imposes significant burdens, both direct, in terms of the costs of prevention and treatment, and indirect, in the form of lost wages – such impacts are, of course, felt more keenly among the poor, for whom they constitute a much greater fraction of available resources (Chima et al. 2003; Teklehaimanot and Mejia 2008). Malaria also has significant effects on human capital formation, with respect to both school absenteeism in areas of high transmission and decreased school performance subsequent to malaria episodes (see e.g., Vitor-Silva et al. 2009). Severe malaria syndromes, including severe anemia and cerebral malaria, can have physiological and neurological sequelae which result in decreased cognitive and reasoning ability, with long-term consequences for intellectual development and productivity (Chima et al. 2003).

In focusing on health, we are more interested in the complementary link, i.e., how SES factors affect malaria risk. Worrall et al. (2005) reviewed a range of micro-level studies, finding strong associations between various SES proxies and uptake of malaria prevention and treatment, but inconclusive evidence for a causal effect of SES on incidence. Filmer (2005), using DHS data for 22 countries, found a general pattern of lower fever in children with higher household SES (measured by a wealth-based asset index), but results were significant in only three countries – the study did not find a significant association of fever in children with mother's years of schooling. Yet the use of fever as a proxy for malaria infection is at best inexact and can result in considerable misclassification, overestimating the impact of uncomplicated episodes but underestimating the consequences of severe disease (Chima et al. 2003) – since 2010, WHO guidelines specify that all suspected cases of malaria should be confirmed via microscopy or rapid diagnostic tests (RDTs) (WHO 2010). Some studies have associated SES factors with severe disease; e.g., in Western Kenya, lower household wealth percentile was associated with higher odds of clinically-confirmed malarial anemia (Siri et al. 2010). Poverty is clearly associated with other factors linked to malaria risk. For example, the poor are less likely to be able to pay for ITNs or other prevention or to seek or obtain adequate treatment. The poor are also more likely to live in sub-standard housing, which allows vectors access to sleeping individuals, thus strongly increasing risk (Lindsay and Snow 1988).

Evidence is inconclusive with respect to the particular effect of adult education on malaria in children. No association was found between maternal education and severe or mild malaria in children in the Gambia (Koram et al. 1995a, 1995b), malaria severity or time to reinfection in Gabon (Luckner et al. 1998), febrile episodes in Benin (Rashed et al. 2000), or malaria infection in Equatorial Guinea (Custodio et al. 2009). In contrast, a study of the relationship of malaria parasitemia with HIV status (Villamor et al. 2003) found that increased maternal education strongly reduced baseline rates of parasitemia, controlling for other indicators of socioeconomic status – in particular, where mothers had no education, children had 43% higher adjusted prevalence. In Mali, maternal primary education halved the risk of severe malaria in children, even though a large majority of educated mothers (84.2%) did not have adequate knowledge about malaria (Safeukui-Noubissi et al. 2004). In Western Kenya, caretaker's level of education was correlated with child parasitemia and malarial anemia in univariate analysis, but not when controlling for other factors (Ong'echa et al. 2006). In Brazzaville, Congo, the odds of presenting with cerebral malaria were 90% higher among children whose mothers had less than a primary school education (Carme et al. 1994). Noor et al. (2006) found that mother's education was strongly predictive of retail sector ITN use in Kenya, one of several studies that have linked maternal education with preventive behavior or treatment seeking (see Worrall et al. 2005).

Just a few studies have attempted to evaluate both causal pathways at once. Both Somi et al. (2007) and de Castro and Fisher (2012) used instrumental variable approaches to try and account for endogeneity (reverse causality) in the relationship between SES and malaria in Tanzania – the former using data from 52 villages within the framework of two major two demographic surveillance sites (DSS), the latter from a 2007-8 special country-wide DHS survey: the HIV/AIDS and Malaria Indicator Survey. Somi et al. (2007) found that household SES was negatively and significantly associated with malaria parasitemia, and that parasitemia, in turn, had a significant negative effect on the wealth-based asset index used to measure wealth. This study used education level of the household head as an instrument, because it showed no association with parasitemia – education of the mother was not among variables considered for analysis. In contrast, de Castro and Fisher (2012) found that malaria illness among young children contributed to lower household wealth, but that lower household wealth did not contribute to a higher incidence of malaria. Further, having either a father or mother with secondary or higher education did not influence malaria risk.

Education of the mother, father or household head is often included as an ancillary variable in studies of socioeconomic determinants of malaria risk, and the preceding discussion is not a comprehensive listing. Yet even a cursory review underscores that education is rarely the primary focus of research. In fact, education (knowledge and skills) is often conflated with economics (resources) – for example, education of the household head may be included in asset-based wealth indices (see e.g., Schellenberg et al. 2003), rendering it inaccessible to analysis as an independent risk factor. Implicitly or explicitly, the focus of many studies is on poverty, even where information on education is collected. In other contexts, it has been shown that the distinction between indicators is critical in estimating impacts of SES factors on health, that these factors act along distinct causal pathways, and that equating them can obscure true relationships (Geyer et al. 2006). Thus, DHS data has been used to show that the effect of mothers' educational attainment on child mortality is often of greater significance than the effect of household wealth, controlling for potential confounders (Fuchs 2010; Pamuk et al. 2011) or that economic development level, household wealth and maternal education have strong independent associations with child health, as indicated by weight and height for age (Boyle et al. 2006). Such conclusions have emerged from other data sources, as well: de Souza et al. (1999) used census and health systems data in Brazil to show that female illiteracy was associated with higher infant mortality. A broad systematic review of global child mortality found that increased educational attainment in women was responsible for more than half of an estimated 8.2 million averted deaths in children younger than 5 years between 1970 and 2009 (Gakidou et al. 2010). As well, various studies have found that maternal education affects infant mortality when controlling for malaria endemicity (Gemperli et al. 2004; Kazembe et al. 2007).

We undertook to measure the independent associations of mother's education and household resources with malaria using DHS/MIS data. A series of studies have recently used MIS data to map risk of malaria parasitemia in various countries (Giardina et al. 2012; Gosoniu et al. 2012; Gosoniu et al. 2010), but while these studies have evaluated the effects of SES (as measured by the DHS wealth index) and, generally, of urban residence, they have not incorporated education in modeling malaria prevalence.

2 Methods

Data sources and variables

Since 1985, the Measure DHS project, funded by USAID, has collected data on demography and health through standardized national surveys (MeasureDHS 2012). The regular DHS survey includes a wealth of information on maternal and child health – including on health behaviors and specific health issues including anemia, malnutrition, malaria, and HIV – fertility and mortality, and a range of individual and household-level socio-demographic factors (Rutstein and Rojas 2006). DHS surveys in malaria-endemic areas have long collected self-reported information about fever and malaria-preventive behaviors, but more recently have begun to include biomarker data, i.e., laboratory-confirmed malaria parasitemia and anemia in children and pregnant women. Since 2006, the new MIS survey, developed in conjunction with Roll Back Malaria, and focused specifically on malaria-relevant information, has been administered in endemic areas, primarily in sub-Saharan Africa (SSA). Twenty-eight MIS surveys and over 300 DHS surveys have been conducted in over 90 countries (MeasureDHS 2012).

We obtained all MIS or DHS datasets available for download from Measure DHS, that report confirmed malaria parasitemia in children (Table 1) – because all of these datasets originate in sub-Saharan Africa, the vast majority of infections are due to *Plasmodium falciparum*, the most lethal malaria parasite (Cibulskis et al. 2011). From these sources, we created country-level and global datasets consisting of records for all children under five with a valid malaria parasitemia test and valid information on maternal education and household wealth. All data processing and statistical analysis was performed in SAS 9.2 (SAS Institute Inc., Cary, NC).

Table 1. Household-level DHS/MIS surveys used in analyses (MeasureDHS 2012).

Country	Year	Survey Type
Angola	2011	MIS
Liberia	2009	MIS
Uganda	2009	MIS
Rwanda	2011	DHS
Senegal	2009	MIS
Tanzania	2008	AIS/MIS
Nigeria	2010	MIS
Madagascar	2011	MIS

We retained a set of explanatory variables, common to all country data sets, which strongly affect malaria risk, in some cases making a judgment as to which of several similar variables was most relevant to the analysis (Table 2). For example, we included whether the child slept under a bednet the previous night as more directly reflective of infection risk than whether the household owns bednets – recognizing the tradeoff that ownership is more easily verified than usage and that these variables capture different aspects of the asset in question. DHS/MIS data contains a multitude of indicators potentially related to malaria occurrence, many of which are highly interrelated; we made an effort to limit predictors – beyond wealth, education, and urban residence, the main variables of interest – to a small set for which there is evidence of strong, direct and consistent effects on malaria incidence, or which are prospectively strong confounders of the relationship between the SES factors of interest and malaria. Where applicable, country-level distributions for explanatory variables and for malaria parasitemia were compared with published summary data (Cosep Consultoria, Consaúde e ICF Macro 2011; Institut National de la Statistique, Programme National de Lutte contre le Paludisme e ICF International 2011; NISR et al. 2012; NMCP et al. 2009; NPC et al. 2012; Ndiaye and Ayad 2009; TACAIDS et al. 2008; UBOS and ICF Macro 2010) for DHS/MIS samples.

Table 2. Contextual, household and individual variables retained.

Variable
Child's age
Whether child slept under insecticide-treated bednet during previous night
Household size (i.e., number of *de jure* members)
Quality of housing (i.e., whether windows and ceilings are made of finished materials)
Mother's age
Mother's educational attainment
Whether household is urban
Household asset-based wealth index constructed from:
Car ownership
Motorcycle ownership
Bicycle ownership
Refrigerator ownership
TV ownership
Radio ownership
Mobile phone ownership
Whether residence has electricity
Whether residence has an improved source of drinking water †
Whether residence has a flush toilet
Number of dwelling rooms in residence
Whether floor of residence is made of finished materials

† According to the WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation definition for improved drinking water sources. http://www.wssinfo.org/definitions-methods/watsan-categories/

Because the standard DHS wealth index often incorporates variables that are likely to independently affect malaria risk (e.g., bednet ownership, quality of housing) (Rutstein and Johnson 2004), we constructed a new asset-based wealth index for each country, following standard methodology (Filmer and Pritchett 2001). Briefly, we used principal components analysis (PCA) of household-related variables (see Table 2) to characterize the underlying distribution of household wealth. PCA identifies linear weighted combinations of variables that explain the largest possible amount of variation in the data; these components capture common information in the original variables, and can be substituted for them to reduce the number of variables under consideration (Vyas and Kumaranayake 2006). When performed using household assets, the first principal component is commonly assumed to represent household wealth, which is difficult to measure directly. We assessed the internal validity of this index by examining the proportion of households in each wealth quintile with the corresponding assets (see Appendix: Table A1).

Statistical Analysis

We first characterized malaria parasitemia by wealth quintile and standard educational attainment categories (i.e., none, primary, secondary or higher), along with urban residence and other covariates. Other continuous variables were also categorized to allow for simple stratified analysis. Bivariate associations between parasitemia and predictors were assessed using Pearson's chi-squared test (Pearson 1900).

As a preliminary step in evaluating the independent effects of maternal education and wealth, we dichotomized these variables – splitting wealth at the median and education at any/no schooling – and compared malaria parasitemia among the four cross-tabulated groups, overall and stratified by urban residence, for each country.

We fit multivariate logistic regression models (Aldrich and Nelson 1984) to the individual country and global data to estimate the magnitude of association of risk factors with malaria parasitemia. In particular, because data from DHS/MIS violate the assumption of independence within sample clusters and countries (i.e., because malaria is an infectious condition and because individuals in the same cluster/country are subject to similar contextual risk factors), we constructed hierarchical multilevel models using the generalized linear mixed modeling procedure (GLIMMIX) in SAS (Kiernan et al. 2012). Such models are appropriate where data has been collected in nested units, as is the case for DHS/MIS surveys. They account for the hierarchical nature of the data, adjusting for the correlation of observations within higher-level groups and allowing observed variance to be apportioned among group-level and individual effects. Sampling cluster was included as a random intercept variable in all models, as was survey country in the model for the global dataset. Other predictors were included as fixed effects. Accordingly, the models allow the intercept to vary randomly with cluster and country, which are assumed to have been selected from larger distributions of possible samples or surveys. We examined variance inflation factors (VIFs) (Velleman and Welsch 1981) to test for potential multicollinearity among the predictor variables.

For individual countries, we fit a minimal model (IA) which extends the cross-tabulated analysis, including categorized education and wealth and urban residence. A full individual country model (IB) incorporates wealth and education as continuous variables (i.e., years of maternal schooling and household wealth percentile), and adds the other covariates: child's age, sleeping under an ITN, housing quality, household size, and age of the mother.

Similarly, we produced minimal (IIA) and full (IIB) models for the global data with education and wealth included as continuous variables. We refined the full model by dropping household size and maternal age, which were both consistently non-significant in earlier iterations, and by considering higher-order terms involving the main variables of interest—both stratified analysis and Box-Tidwell tests suggested non-linear effects for education and wealth. The Box-Tidwell test adds a continuous variable along with its Box-Tidwell transformation ($x * \log(x)$) to the logistic regression model. A significant effect for the transformed variable indicates violation of the assumption of linearity (Box and Tidwell 1962).Thus, we evaluated quadratic (x^2) terms and interactions (i.e., *education * wealth*, *education * urban residence*, and *wealth * urban residence*), either of which can result in nonlinear effects. Initial examination of VIFs when higher-order terms were included indicated significant multicollinearity among potential predictors, so we centered wealth percentile and years of education around their grand means and used the centered variables to generate higher-order terms; subsequently, no major multicollinearity was observed (i.e., all VIFs were under 4.0). We took an incremental approach, adding quadratic terms, assessing significance and model fit, and then adding interactions to produce the final model (IIC) – in fact, no interactions were found to have significant effects.

3 Results

Exploratory data analysis

Table 3 shows bivariate associations between malaria parasitemia in children and explanatory variables. Of these, links with wealth, schooling and housing quality are significant in all countries, with trends in the expected directions, i.e., increasing wealth and maternal education are associated with lower levels of infection, as is living in a house with finished windows and ceilings. Malaria decreases with urban residence and increases with child's age (Figure 1) in all countries, as expected. These relationships are statistically significant in all countries but Rwanda, where the extremely low prevalence (~2%) may play a role. Other covariates are significantly associated with prevalence only in some contexts. Children who slept under an ITN the previous night have lower parasitemia in seven of eight countries than those who didn't, yet these differences are significant in only three countries. In Madagascar, parasitemia is significantly higher among such children, a surprising result which may reflect the mass distribution of nets to households in vulnerable regions. Household size is statistically significant in five countries – in each of these, prevalence increases with the number of residents. Mother's age is significantly associated with malaria in four countries, but patterns vary with context.

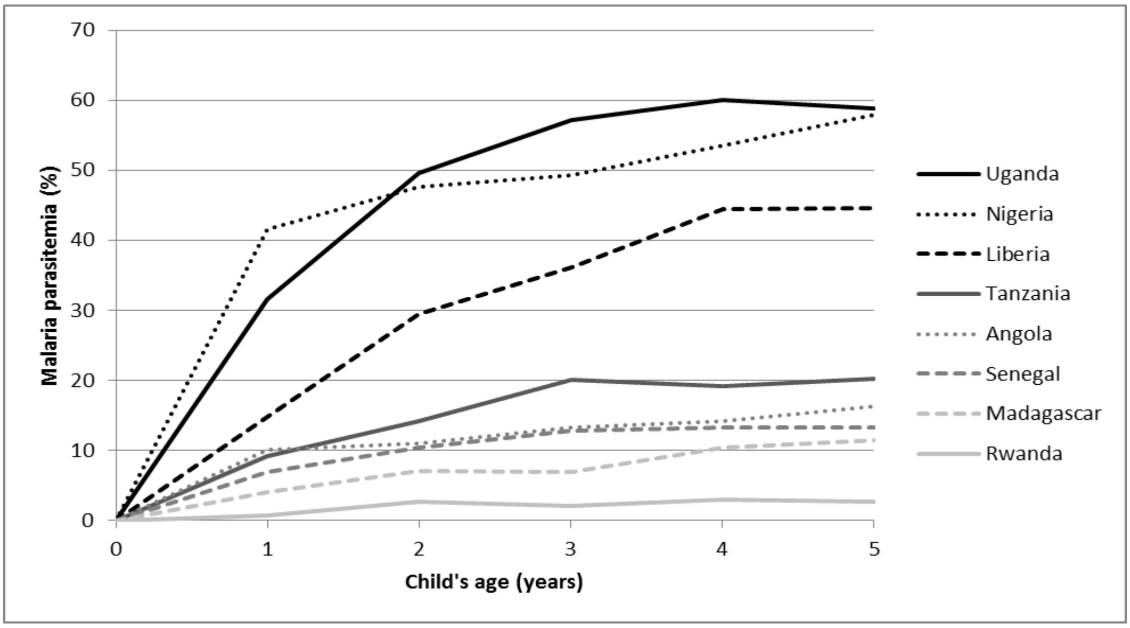

Figure 1. Prevalence of malaria parasitemia in children by age and country

Table 3. Malaria parasitemia by contextual, household, and individual risk factors: parasite rate (% of population).

	Angola (n = 2,924)	Liberia (n= 3,042)	Uganda (n = 3,400)	Rwanda (n = 3,699)	Senegal (n = 3,562)	Tanzania (n = 5,600)	Nigeria (n = 4,353)	Madagascar (n = 5,257)
Residence location	***	***	***		***	***	***	***
Rural	18.3 (68.6)	40.5 (63.1)	54.0 (88.0)	2.5 (88.5)	14.5 (64.1)	19.0 (83.4)	55.2 (76.8)	8.8 (94.4)
Urban	1.7 (31.4)	24.9 (37.0)	31.8 (12.0)	1.1 (11.5)	7.2 (35.9)	7.0 (16.6)	36.8 (23.2)	1.9 (5.6)
Mother's highest level of schooling	***	***	***	*	***	***	***	***
None	20.3 (35.2)	38.3 (51.9)	55.7 (21.7)	3.9 (19.4)	13.3 (69.4)	21.2 (24.9)	57.9 (51.5)	9.5 (27.9)
Primary	10.1 (55.2)	36.1 (29.9)	53.7 (62.5)	2.0 (72.2)	9.0 (22.8)	16.3 (70.9)	53.7 (19.8)	9.3 (54.3)
Secondary+	3.2 (9.7)	22.3 (18.2)	35.6 (15.8)	2.1 (8.4)	7.5 (7.9)	3.3 (4.3)	36.4 (28.7)	4.1 (17.9)
Wealth quintile	***	***	***	***	***	***	***	***
I (lowest)	22.2 (19.3)	40.7 (13.2)	57.8 (18.0)	4.3 (17.7)	24.0 (14.8)	21.3 (24.7)	59.9 (22.4)	13.9 (22.6)
II	22.9 (21.3)	40.8 (22.6)	54.5 (21.4)	3.3 (23.3)	13.7 (14.4)	19.6 (23.0)	59.3 (22.0)	10.8 (20.9)
III	12.6 (21.2)	40.0 (19.0)	54.4 (20.7)	1.2 (20.1)	11.9 (17.4)	19.8 (18.7)	57.3 (19.8)	7.4 (20.3)
IV	5.2 (19.8)	33.6 (21.5)	53.3 (20.3)	1.6 (20.1)	7.7 (21.6)	13.8 (17.5)	44.7 (18.2)	5.9 (21.0)
V (highest)	1.1 (18.4)	22.1 (23.8)	34.8 (19.6)	1.4 (18.8)	7.8 (31.9)	6.4 (16.1)	28.9 (17.6)	1.8 (15.2)
Child's age (months)	*	***	***		**	***	***	***
6-11	10.1 (13.3)	14.7 (14.0)	31.5 (19.7)	0.7 (10.8)	6.9 (9.6)	9.1 (13.5)	41.6 (12.4)	4.0 (11.9)
12-23	11.0 (23.9)	29.4 (25.1)	49.6 (22.0)	2.6 (21.1)	10.3 (23.9)	14.1 (24.8)	47.6 (22.1)	7.1 (20.5)
24-35	13.2 (22.3)	36.1 (21.1)	57.2 (19.9)	2.0 (23.8)	12.8 (21.8)	20.0 (22.2)	49.3 (20.4)	6.9 (22.3)
36 +	15.1 (40.6)	44.5 (39.8)	59.4 (38.4)	2.8 (44.3)	13.3 (44.7)	19.8 (39.6)	55.8 (45.2)	10.9 (45.4)
Child slept under an ITN	***		**	***				**
No	14.9 (73.0)	35.7 (71.2)	53.4 (64.8)	3.6 (29.4)	11.9 (67.2)	17.6 (65.6)	51.5 (69.1)	6.2 (22.8)
Yes	8.1 (27.0)	32.3 (28.9)	47.5 (35.2)	1.8 (70.7)	11.8 (32.8)	15.8 (34.5)	49.6 (30.9)	9.1 (77.2)
Finished windows and ceilings	***	***	***	**	***	***	***	***
No	17.8 (69.0)	39.9 (68.2)	54.2 (75.1)	3.0 (54.0)	16.3 (39.9)	20.7 (73.7)	57.4 (61.1)	9.4 (84.4)
Yes	2.5 (31.0)	23.8 (31.8)	42.8 (24.9)	1.5 (46.0)	8.8 (60.1)	6.7 (26.4)	40.8 (38.9)	3.1 (15.6)
Household size		*	**			*	**	*
1-4	11.3 (25.3)	31.1 (20.5)	45.8 (26.1)	2.5 (36.9)	13.3 (3.9)	15.7 (23.8)	47.2 (19.1)	7.9 (28.8)
5-6	14.8 (37.9)	36.4 (30.1)	53.4 (33.2)	2.4 (35.9)	11.3 (11.0)	15.7 (30.8)	49.2 (29.3)	7.5 (34.4)
7-8	12.7 (22.9)	38.1 (19.1)	53.1 (25.6)	1.8 (20.1)	11.6 (12.7)	17.3 (22.0)	53.0 (21.4)	8.7 (21.0)
9 +	12.1 (13.9)	33.5 (30.2)	53.1 (15.1)	2.7 (7.1)	11.9 (72.4)	19.6 (23.4)	53.5 (30.2)	10.9 (15.9)
Mother's age (years)		***			**	*		*
< 20	9.1 (11.0)	32.7 (6.9)	45.6 (4.9)	2.7 (1.0)	13.2 (4.9)	19.5 (4.3)	54.2 (4.3)	7.9 (7.2)
20-29	12.8 (54.2)	31.4 (50.2)	51.1 (55.6)	2.4 (46.8)	10.1 (48.7)	16.8 (51.8)	50.1 (47.2)	8.5 (47.4)
30-39	14.7 (28.4)	39.8 (33.1)	51.0 (31.6)	2.1 (39.2)	14.2 (38.3)	15.8 (34.9)	51.2 (37.7)	7.5 (35.4)
40 +	14.9 (6.3)	36.6 (9.8)	57.5 (8.0)	2.9 (13.0)	10.6 (8.2)	21.1 (8.9)	52.4 (10.7)	11.7 (10.1)

Chi-squared test: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

A simple way to evaluate the relative effects of education and wealth is to look at malaria parasitemia across different strata of these variables. Table 4 shows this relationship, both overall and decomposed by urban/rural residence. For the complete sample, results are largely as expected: in almost every case, infection is highest where maternal education and household wealth are low, and lowest in the high/high category, with high wealth and education each independently associated with decreased risk. The exception is in Uganda, where among those with low maternal education, high wealth is associated with higher childhood infection than low wealth; however, the difference in rates is small and non-significant. In the disjoint cases (low/high, high/low), high wealth is usually associated with a greater decrease in parasitemia than high education. There is some evidence of departure from additivity in the joint effects of maternal education and household wealth, as in six out of eight countries, the reduction in parasitemia associated with having both high wealth and high education exceeds the sum of the reductions from either alone – this is especially true in Uganda, Tanzania and Nigeria.

Table 4. Malaria parasitemia by any/no maternal education and above/below median wealth, stratified by urban residence.

	Rural				Urban				Total			
Education / Wealth	Low/ Low	Low/ High	High/ Low	High/ High	Low/ Low	Low/ High	High/ Low	High/ High	Low/ Low	Low/ High	High/ Low	High/ High
Angola	22.7	14.4	19.9	9.0	0[†]	6.9	4.9[†]	1.1	22.6	12.0	19.1	3.9
Liberia	43.6	31.2	41.9	39.3	32.7[†]	29.1[†]	24.6[†]	21.1	42.1	30.2	38.5	27.3
Uganda	56.7	60.3	57.2	48.3	41.5[†]	27.5[†]	65.2	24.0	56.6	54.5	57.4	43.1
Rwanda	4.6	3.7	2.7	1.3	0	0	3.7	0.1	4.3	3.4	2.7	1.2
Senegal	18.2	8.2	15.2	7.6	4.3[†]	7.1	4.7	5.7	16.8	7.7	12.5	6.3
Tanzania	21.1	22.6	19.4	15.9	32.2	12.8	16.1	3.9	21.5	20.9	19.3	12.1
Nigeria	59.9	55.6	56.8	47.2	60.5	39.5	56.3	30.2	60.0	52.3	56.8	39.9
Madagascar	12.6	6.8	12.4	5.3	16.2[†]	0	1.9[†]	1.9	12.6	6.6	12.3	4.9

[†] Less than 50 observations in category

A considerably more complex situation occurs when stratifying by urban residence. In urban areas, five of eight countries deviate from the expected relationship; i.e., the high/high and low/low classes are not associated with the highest or lowest parasitemias, respectively. In Angola, Rwanda, Senegal and Madagascar, the magnitude of the deviation is minor, and small urban sample sizes and low rates of infection likely account for these patterns. In urban residents of Uganda, however, in the low wealth category, higher maternal education is associated with much higher childhood malaria prevalence (65.2% versus 41.5%) – small sample sizes (< 20) may again be a factor. In rural areas, observed values are more consistent with expectations, with a few exceptions: in rural Ugandans, children with low wealth and maternal education have lower prevalence than those with either high wealth or education (but not both); in residents of rural Liberia, increased education is associated with a higher prevalence (39.3% vs. 31.2%) among those with high household wealth. Across residence strata, high wealth is more often associated with a greater decrease in parasitemia than high education, but there is considerable variation.

Country-specific models

Table 5 shows odds ratios (ORs) for infection for urban residence, mother's educational attainment categories, and wealth quintiles from the country-specific reduced models (IA). The mean OR for urban residence is 0.43, i.e., children living in urban areas experience 57% lower odds of malaria infection relative to rural residents. Maternal schooling and household wealth are associated with monotonic decreases in odds of infection, as clearly shown in Figure 2, although education is less often statistically significant than wealth. All significant odds ratios are less than one. Being in the highest wealth quintile is associated with decreases in parasitemia about equal to those experienced by urban residents.

Table 5. Odds ratios for malaria parasitemia in children from country-specific reduced (IA) hierarchical logistic regression models.

Variable	Angola (n = 2,924)	Liberia (n = 3,042)	Uganda (n = 3,400)	Rwanda (n = 3,699)	Senegal (n = 3,562)	Tanzania (n = 5,580)	Nigeria (n = 4,353	Madagascar (n = 5,257)
Urban residence	0.17**	0.78	0.17***	0.53	0.54***	0.37**	0.38***	0.53
Mother's highest level of schooling (vs. none)								
Primary	0.98	0.91	0.92	0.51*	0.99	1.10	1.08	1.06
Secondary +	0.83	0.68**	0.56***	1.03	0.84	0.28**	0.72*	0.92
Wealth quintile (vs. lowest)								
II	1.27	0.69*	1.12	0.77	0.63*	0.76*	0.96	0.74
III	0.87	0.69*	0.83	0.29**	0.69*	0.83	0.97	0.76
IV	0.60	0.65*	0.79	0.33*	0.47**	0.54***	0.86	0.72
V	0.18**	0.43***	0.60**	0.25*	0.51*	0.39***	0.48***	0.30***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

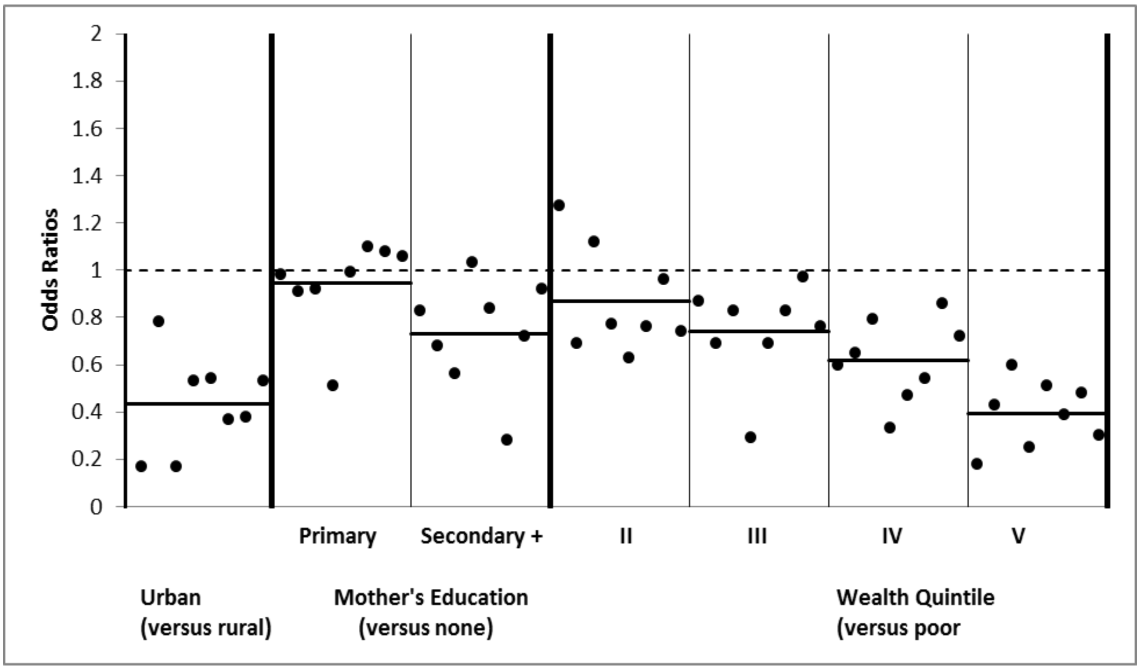

Figure 2. Country-specific and mean odds ratios for malaria parasitemia in children for urban residence, maternal education category and wealth quintile from country-specific reduced (IA) hierarchical logistic regression models.

Full country-level models (IB) paint a similar picture (Table 6). Wealth is always associated with decreased parasitemia, nearly always significantly. Urban residents are also subject to substantially lower risks in all countries, though significantly in just five. Maternal education is significantly associated with reduced risk only in Liberia and Uganda, though decreased risk accompanies schooling in most countries. Among covariates, child's age is strongly and consistently coupled with lower risk of infection, while ITN use and housing quality are associated with decreased risk in most countries, but not always significantly. Household size and maternal age display varied patterns across countries and never attain overall significance in the model, although several individual levels of mother's age are significantly related to lower risk in Liberia.

Table 6. Odds ratios for malaria parasitemia in children from country-specific full (IB) hierarchical logistic regression models.

	Angola	Liberia	Uganda	Rwanda	Senegal	Tanzania	Nigeria	Madagascar
Urban residence	0.23*	0.74	0.17***	0.77	0.55*	0.32***	0.37***	0.45
Mother's schooling	0.96	0.96**	0.94***	0.93	0.99	1.00	0.99	0.99
Wealth percentile	0.99	0.99***	0.995*	0.99*	0.99***	0.99**	0.99**	0.99**
Child's age (months)								
6-11	REF	REF	REF	REF	REF	REF	REF	REF
12-23	1.10	2.28***	3.85***	5.96*	1.22	1.96***	1.30	2.18*
24-35	1.82*	4.42***	5.58***	3.45	1.60	3.04***	1.94	2.56**
36 +	2.09**	6.34***	6.21***	6.56**	2.07**	3.19***	2.27***	3.57***
Child slept under ITN	0.80	0.79*	0.67***	0.38**	1.11	0.84	0.86	0.82
Finished windows and	0.36*	0.91	0.81	0.99	1.33	0.64**	0.81	0.75
Household size								
1-4	REF	REF	REF	REF	REF	REF	REF	REF
5-6	1.39	1.25	1.19	0.85	0.81	0.87	1.09	0.79
7-8	1.48	1.13	1.07	0.43	0.73	0.84	1.24	0.98
9 +	1.41	1.17	1.00	1.60	1.03	1.05	1.12	1.09
Mother's age (years)								
< 20	REF	REF	REF	REF	REF	REF	REF	REF
20-29	1.53	0.64*	0.89	1.03	0.99	0.71	0.79	1.28
30-39	1.41	0.70	0.67	0.62	1.34	0.64	0.78	0.95
40 +	1.52	0.62*	0.84	0.91	1.06	0.66	0.80	1.78

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Global models

The global hierarchical models (Table 7) estimate effects that are substantially similar to the mean of country-specific estimates. The final model (IIC) excludes household size and mother's age, which were not found to have significant effects in earlier formulations, and adds quadratic terms for wealth and education. Because none of the interaction terms among the three main variables of interest (i.e., *education * wealth*, *education * urban residence*, and *wealth * urban residence*) attained statistical significance with the quadratic terms in the model, we excluded them in the final formulation. Figure 3 illustrates the predicted probabilities of infection with variation in maternal educational attainment and household wealth percentile for urban and rural areas. Overall, the factor associated with the greatest reduction in risk is urban residence, which decreases the odds of infection by close to 60%. Sleeping under an ITN or having high-quality housing account for moderate reductions of 20% and 15% respectively.

Table 7. Odds ratios and confidence intervals for malaria parasitemia in children from global dataset hierarchical logistic regression models: reduced (IIA), full (IIB) and final, incorporating higher-order terms (IIC).

	IIA	95% C.I.	IIB	95% C.I.	IIC	95% C.I.
Urban residence (URB)	0.38***	(0.29, 0.49)	0.40	(0.30, 0.52)***	0.43***	(0.33, 0.56)
Mother's schooling	0.96***	(0.95, 0.98)	0.97	(0.96, 0.98)***	0.98*	(0.97, 1.00)
EDU^2	--	--	--	--	0.997*	(0.99, 1.00)
Wealth percentile (WLT)	0.99***	(0.99, 0.99)	0.99	(0.99, 0.99)***	0.99***	(0.99, 1.00)
WLT^2	--	--	--	--	1.000***	--
Child's age (months)	--	--				
6-11			REF	REF	REF	REF
12-23			2.14	(1.85, 2.47)***	2.17***	(1.88, 2.51)
24-35			3.22	(2.78, 3.73)***	3.01***	(2.61, 3.48)
36 +			3.90	(3.41, 4.47)***	3.81***	(3.33, 4.35)
Child slept under ITN	--	--	0.79	(0.71, 0.88)**	0.80**	(0.72, 0.89)
Finished windows and	--	--	0.82	(0.71, 0.95)*	0.85*	(0.73, 0.99)
Household size	--	--			--	--
1-4			REF	REF		
5-6			1.07	(0.96, 1.20)		
7-8			1.05	(0.92, 1.19)		
9 +			1.10	(0.97, 1.26)		
Mother's age (years)	--	--			--	--
< 20			REF	REF		
20-29			0.92	(0.77, 1.10)		
30-39			0.88	(0.73, 1.05)		
40 +			0.94	(0.76, 1.16)		

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

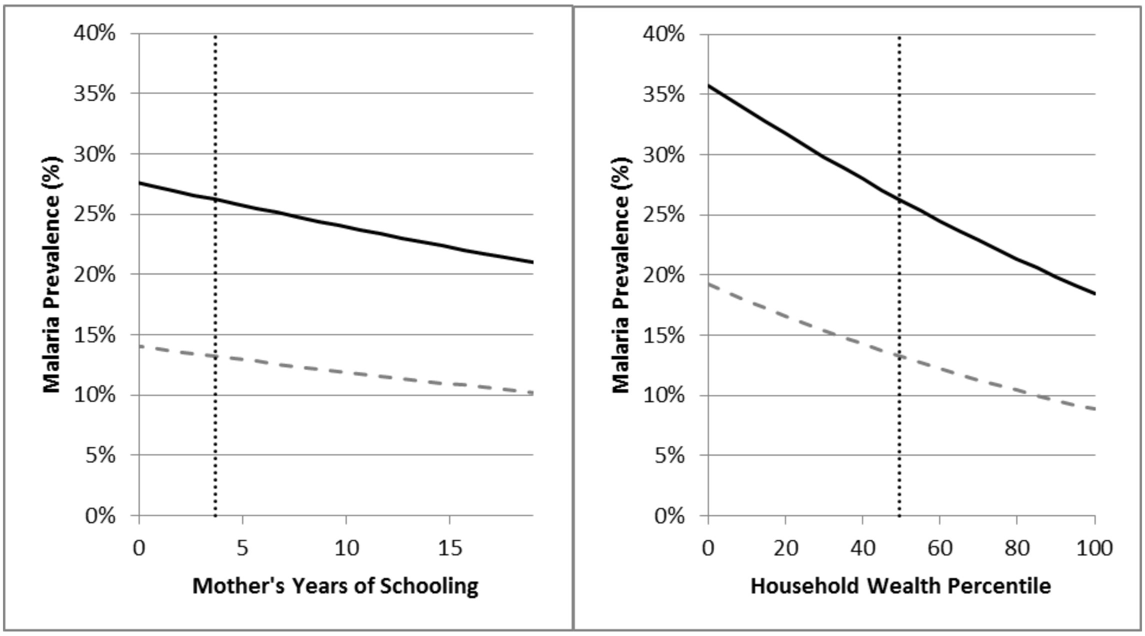

Figure 3. Model-predicted probability of malaria infection versus maternal schooling and household wealth, by rural (solid line) and urban (dashed line) residence. The vertical dotted line represents the mean years of schooling (left) or wealth percentile (right).

4 Discussion

In this sample derived from DHS/MIS data, maternal education, independently of household resources, plays an important role in childhood malaria risk. Evaluated at the endpoints of their ranges, the magnitude of the association between higher maternal education and lower malaria in children is somewhat smaller than the equivalent association for household resources, yet it is still substantial and statistically significant. In our model, completion of six years of primary school in a rural area reduces odds of malaria infection by about 14% (OR= 0.86), whereas increasing from the lowest wealth percentile to the 40th (equivalent to the lower end of the middle wealth quintile) reduces risk by 26% (OR = 0.74) – in urban areas, the reductions in odds of infection are substantially higher (OR = 0.68 and 0.45 respectively. The absolute values of these figures appear to lie within the range observed in previously published data, although precise comparisons are difficult because the measures used and outcomes vary widely across studies. For example, Somi et al. (2007), found a one-unit increase in asset-based wealth PCA score, where the range of PCA scores across all individuals was 11.1, to decrease parasitemia by 4%; Siri et al. (2010) estimated a 10% increase in wealth percentile to decrease malarial anemia risk by 20% in an urban area.

The inclusion of higher-order terms is rare in analyses of socio-demographic or contextual risk factors for malaria, yet such relationships are quite likely. A small increase in resources may make a great deal of difference to a poor household, in terms of its ability to provide in ways that reduce a child's malaria risk, while a similar increase may make little difference for wealthy households that already make use of available malaria prevention and treatment opportunities. In the same vein, a few years of education at the primary level, in addition to (perhaps) providing knowledge about malaria, are likely to boost basic life skills, familiarity with and trust of the public health system, self-reliance, and a host of other factors which affect risk, whereas a few extra post-secondary years may be of lesser import. Similarly, interactions among wealth, education and urban context are to be expected. For example, the ability of individuals to make use of their knowledge and skills should, in fact, depend on their economic resources, and vice versa. The extent to which mothers are able to capitalize on education or wealth may depend on the distance to or the absolute availability of prevention or control measures or other factors which may vary significantly across levels of urbanization. In this study, we found small but significant nonlinearities in the relationships between the logit of malaria parasitemia and wealth and education. Nonlinear effects can result from interactions or from polynomial relationships of the outcome with particular independent variables, or both - our model attributes these to the latter, but a different model selection process might specify a greater role for interaction terms. Nevertheless, observed effect sizes are small, and our main results are relatively insensitive to the choice of higher-order terms.

Our model improves upon previous uses of DHS data to evaluate the association of malaria risk with SES factors by incorporating confirmed parasitemia rather than self-reported fever (as in Filmer 2005), and by separating out the independent effect of education. As well, it complements prior studies with DHS (Fuchs 2010; Pamuk et al. 2011) that have demonstrated a significant effect for maternal education, independent of wealth, on infant mortality. In the latter, education was generally found to be a more reliable and stronger predictor of health than wealth, whereas our results suggest the opposite. It may be that infant mortality encapsulates such a range of disease syndromes and potential risk factors that the ability of mothers to flexibly apply knowledge and skills is more important than for malaria, where interventions are generally well-defined, but often costly. Moreover, the dramatic acceleration in efforts to combat malaria in the African continent over the past decade may, in some cases, have saturated surveyed populations with information on malaria causes, prevention and treatment, dampening some the direct benefits of maternal education (though not the indirect effects, such as increased self-reliance).

As expected, urban residence was an extremely strong predictor of malaria risk; urban residents were less than half as likely to be infected, after controlling for other factors. Broad evidence exists for the reduction of malaria prevalence in cities (Hay et al. 2005; Keiser et al. 2004; Robert et al. 2003). An effort to relate *P. falciparum* prevalence to urban extents at global scale found the median parasite rate in urban areas to be about 40% that in rural areas (Tatem et al. 2008), which agrees well with our results. Two other studies using MIS data estimated similar odds ratios for urban residence: 0.42 in Tanzania (Gosoniu et al. 2012), and 0.43 in Senegal (Giardina et al. 2012), though this relationship was only statistically significant in the former. Our country-specific regressions estimated substantial variation in the effect of urbanization across countries (OR = 0.17 – 0.77). One way to further specify the effect of contextual risk factors would be to link the GPS locations of sampled clusters to continent-wide maps of population distribution and of malaria risk, and incorporate local averages in regression modeling.

Sleeping under an ITN was found to reduce the odds of prevalence of malaria parasitemia by ~20%, controlling for other factors. This is close to the level observed in a study that used very similar DHS/MIS data to ours: Lim et al. (2011) found a pooled mean reduction in prevalence in children from sleeping under an ITN of 24%. The small difference in estimated effect may arise from the inclusion of different countries/surveys in the overall dataset (e.g., the Lim et al. study used data for Zambia, but not for Nigeria or Madagascar, in estimating effects on parasitemia prevalence) or the specification of different covariates (e.g., their use of the original DHS wealth index and the non-inclusion of housing quality). We identified a similar negative association of housing quality with malaria prevalence; living in a house with improved roof and ceiling was associated with a ~15% relative reduction of parasitemia prevalence, controlling for other factors. ITNs and quality housing both act as barriers to transmission while sleeping in the household; however, ITNs also act by killing resting mosquito vectors, so it is consistent with theory that its pooled effect was larger in magnitude. Unlike some previous studies, we did not find significant effects for household size or mother’s age, nor did we find their inclusion to appreciably affect estimates for the effects of wealth or education.

We have identified a strong independent effect of education on malaria risk, using confirmed malaria parasitemia in a range of countries across sub-Saharan Africa, controlling for other SES factors. Education is valuable in its own right, as a critical element of self-determination, human rights and social justice, but the current study provides yet more evidence that it also is an important determinant of health. It is worth noting that the effects of education on malaria extend beyond simply the acquisition of knowledge – indeed, other studies (e.g., Safeukui-Noubissi et al. 2004) have noted that education lowers malaria risk even where specific knowledge is lacking; likely, education encompasses less-tangible factors such as self-sufficiency, motivation and confidence which can lead to improved outcomes on a broad front.

There are important reasons to consider the effects of education on malaria prevalence and incidence. For one, policies to promote education are often substantially different than those aimed at reducing poverty or at controlling malaria in the short-term, yet such policies may yield important co-benefits for malaria control. Indeed, other work has shown that rising standards of living, including education and consequent shifts in occupation, are in many contexts a precursor – if not a precondition – for malaria elimination (Humphreys 2001). Second, the provision of education has an inertia, a persistency that does not exist for other interventions (Lutz 2009). Malaria control is too often envisioned as a response to immediate or short-term needs, and resurgence often follows the reduction or cessation of activities. Economic resources, too, are subject to considerable variation at household, community and national scales, whereas education, once attained, is long-lasting (though skills and knowledge may eventually wane), with effects that are felt for decades, even when funding ceases. Given the current shortfalls in funding for global malaria control and the lingering effects of the global financial crisis, it makes sense to add measures that act over the long term to the arsenal of malaria control tools. Third, among research needs that have been identified as critically important as countries move to lower prevalence is a better understanding of distributional aspects of malaria (Marsh 2010); it is clear that maternal education significantly influences such distributions. Finally, beyond the potential for maternal education as a policy lever for combating malaria, our results suggest the utility of including it as a factor in projections of future endemicity and health costs. In other contexts, it has been shown that taking account of educational attainment in multi-state projection models of specific health outcomes leads to significantly different conclusions about the health and needs of future populations (Batljan et al. 2009; Loichinger 2012). If the current climate of optimism and relatively high funding does not lead to the highly-anticipated elimination of malaria in much of the world, it may well be that ensuring education for all, and particularly for women, yields substantial and lasting reductions in prevalence in many situations.

Among the main limitations of this work are the potential for reverse causality, misspecification in variable construction or ascertainment, exclusion of important variables, and differential recall of information by sampled subgroups.

We did not address the issue of reverse causality here. For this combination of independent variables and outcome, causality is almost inevitably in the expected direction; i.e., it is reasonable to suppose that household wealth, which reflects assets built up over the long-term rather than instantaneous availability of funds, precedes and influences acute infection in the child – this is even more true for maternal educational attainment, which in most cases will have predated the child's birth. Yet, to the extent that infection in the child reflects risk to all other members of the household, the long-term pattern of infection may indeed influence SES factors in this context. Where endogeneity is present, unidirectional studies are likely to overstate the influence of risk factors. More studies along the lines of Somi et al. (2007) and de Castro and Fisher (2012) are needed to evaluate the direction of causality in this relationship, but they should assess this for education in addition to wealth, incorporating new DHS/MIS and other data as it becomes available.

Considerable potential for misspecification exists within the DHS/MIS data. Wealth, in particular, is difficult to measure or even accurately to conceptualize in comparative studies – it is not necessarily clear whether the resources most likely to affect health are the immediate availability of funds for acute care or long-term assets and stability, which affect nutrition, education, and many other factors. Moreover, assets owned vary considerably from country to country and from rural to urban areas, such that indices that attempt to capture multiple settings likely misclassify a substantially large proportion of households. The wealth-based asset index, nevertheless, has become a standard tool for cross-country comparisons; results using asset indices compare favorably with direct measures of household consumption or other economic indicators (Filmer and Scott 2012) and are usually much easier to obtain. Educational content and quality, too, varies, such that equating years of schooling cross-nationally may be misleading. It would be of interest to consider more comparable outcomes such as literacy or numeracy, but these are perhaps less relevant to policy decision-making than years of schooling. ITN use may have substantially different implications depending on the specific measure (e.g., sleeping under an ITN the previous night versus household ITN ownership), though Lim et al. (2011) found nearly identical effects for these two predictors using DHS/MIS data. Housing made of finished materials may or may not have open eaves, which allow for mosquito entry and thus infection (Lindsay & Snow, 1988). We recognize the potential for misspecification, but where possible have made an effort to show that our results are comparable to previous work.

A potentially greater problem is the failure to include all relevant variables. Our goal in this study was to demonstrate the independent effect of maternal education on malaria risk, and we opted for a minimal set of explanatory variables for simplicity and clarity, and to maximize the number of observations relative to predictors. Yet a wide range of other variables that affect malaria risk are already available or potentially available from some DHS/MIS datasets, and others could be associated through GIS/RS analyses, and indeed have been in some cases. Among these are community-level endemicity and environmental factors, community-level wealth and education, recent household IRS, variables related to household composition or the household head, and/or national-level economic or policy factors. Further studies are needed, incorporating these variables for a wider range of DHS/MIS studies. Indeed a major limiting factor in this analysis was the availability for public use of only 8 of the 28 studies which have collected data on malaria parasitemia; the timely release of other datasets relevant to malaria risk is critical to effective research.

Finally, there is the possibility that differential recall or reporting of SES factors between the more and less educated/wealthy could bias the results. Those with a better understanding of the causes of malaria or more direct exposure to, for example, information campaigns, may be more likely to identify factors that contribute to illness in their families, which could lead to an overestimation of the effect of risk factors in this context. Such an effect may have contributed to the unusually high prevalence we observed among those with high education but low wealth in Uganda, though small sample sizes probably played a role.

5 Conclusion

The main finding of this study is that maternal education and household wealth are each independently associated with lower malaria parasitemia in children, though the magnitude of the relationship tends to be larger for household wealth. Urban residence was associated with a greater reduction than any other factor, more than halving malaria risk, while ITN usage and high-quality housing were associated with moderately decreased risk. These findings have important implications for projections of the long-term prevalence of disease and for the policy discourse surrounding malaria control and prevention. Future research on socioeconomic determinants of malaria risk should clearly distinguish between the effects of education and wealth, seek to establish the causality of the relationships involved, and evaluate the extent to which interactions among these factors and others like endemicity and community-level variables affect risk. DHS/MIS data can be useful in this regard, especially as more MIS studies are released for research purposes, but other data that evaluates quality of education and examines the multiple pathways via which SES factors affect risk are needed.

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Appendix

Table A1. Validation of asset-based wealth index

	Wealth Category		
Country/Variable	Quintiles I & II (poorest)	Quintiles III & IV	Quintile V (wealthiest)
Angola			
Asset ownership (proportion)			
Car	0.0000	0.0373	0.4479
Motorcycle	0.0692	0.2184	0.1641
Bicycle	0.1342	0.1239	0.1709
Refrigerator	0.0000	0.0659	0.7385
TV	0.0068	0.5555	0.9795
Radio	0.2523	0.7756	0.9487
Mobile phone	0.0321	0.7262	1.0000
Access to utilities/infrastructure (proportion)			
Electricity	0.0068	0.3068	0.9521
Improved drinking water source	0.1840	0.6153	0.8137
Flush toilet	0.0143	0.2114	0.6376
Characteristics of living residence			
Number of dwelling rooms (*mean*)	1.484	1.996	2.325
Floor of finished materials	0.0025	0.4133	0.9795
Liberia			
Asset ownership (proportion)			
Car	0.0000	0.0000	0.0488
Motorcycle	0.0000	0.0151	0.1514
Bicycle	0.0000	0.0092	0.1088
Refrigerator	0.0000	0.0000	0.0389
TV	0.0000	0.0008	0.2268
Radio	0.1249	0.5943	0.8728
Mobile phone	0.0000	0.4174	0.8885
Access to utilities/infrastructure (proportion)			
Electricity	0.0000	0.0008	0.0531
Improved drinking water source	0.4342	0.7972	0.8992
Flush toilet	0.0000	0.0042	0.2535
Characteristics of living residence			
Number of dwelling rooms (*mean*)	1.773	2.316	2.655
Floor of finished materials	0.0265	0.3797	0.8469
Uganda			
Asset ownership (proportion)			
Car	0.0000	0.0000	0.0599
Motorcycle	0.0000	0.0398	0.2244
Bicycle	0.3457	0.5923	0.4896
Refrigerator	0.0000	0.0000	0.1425
TV	0.0000	0.0000	0.3107
Radio	0.3874	0.8551	0.8670
Mobile phone	0.0290	0.6547	0.8929
Access to utilities/infrastructure (proportion)			
Electricity	0.0000	0.0023	0.3193
Improved drinking water source	0.5859	0.7928	0.8943
Flush toilet	0.0000	0.0000	0.0418
Characteristics of living residence			
Number of dwelling rooms (*mean*)	1.576	2.166	2.243
Floor of finished materials	0.0000	0.0968	0.8313
Rwanda			
Asset ownership (proportion)			
Car	0.0000	0.0000	0.0347
Motorcycle	0.0000	0.0000	0.0400
Bicycle	0.0592	0.2331	0.3267
Refrigerator	0.0000	0.0000	0.0520
TV	0.0000	0.0027	0.2621
Radio	0.2544	0.8770	0.8840

Mobile phone	0.0545	0.5728	0.8907
Access to utilities/infrastructure (proportion)			
Electricity	0.0000	0.0055	0.4291
Improved drinking water source	0.5431	0.8250	0.8703
Flush toilet	0.0000	0.0000	0.0402
Characteristics of living residence			
Number of dwelling rooms (*mean*)	1.767	2.270	2.812
Floor of finished materials	0.0000	0.0314	0.6933
Senegal			
Asset ownership (proportion)			
Car	0.0090	0.0169	0.0526
Motorcycle	0.0179	0.0942	0.1954
Bicycle	0.2638	0.1847	0.1310
Refrigerator	0.0000	0.0125	0.5024
TV	0.0090	0.3922	0.8938
Radio	0.6570	0.8756	0.9611
Mobile phone	0.5037	0.9198	0.9644
Access to utilities/infrastructure (proportion)			
Electricity	0.0037	0.3856	0.8969
Improved drinking water source	0.4664	0.7226	0.9277
Flush toilet	0.0202	0.3797	0.8066
Characteristics of living residence			
Number of dwelling rooms (*mean*)	3.762	5.628	5.964
Floor of finished materials	0.0874	0.5644	0.8173
Tanzania			
Asset ownership (proportion)			
Car	0.0000	0.0000	0.0417
Motorcycle	0.0000	0.0023	0.1044
Bicycle	0.3630	0.6323	0.5647
Refrigerator	0.0000	0.0000	0.2080
TV	0.0000	0.0000	0.3607
Radio	0.3086	0.7827	0.8762
Mobile phone	0.0000	0.3017	0.8959
Access to utilities/infrastructure (proportion)			
Electricity	0.0000	0.0018	0.4298
Improved drinking water source	0.2250	0.6364	0.8341
Flush toilet	0.0000	0.0009	0.1622
Characteristics of living residence			
Number of dwelling rooms (*mean*)	1.996	2.751	2.842
Floor of finished materials	0.0000	0.1958	0.9024
Nigeria			
Asset ownership (proportion)			
Car	0.0035	0.0473	0.3390
Motorcycle	0.3098	0.4957	0.4261
Bicycle	0.3419	0.2937	0.1343
Refrigerator	0.0000	0.0427	0.6367
TV	0.0210	0.5211	0.9652
Radio	0.5009	0.8275	0.8991
Mobile phone	0.2174	0.8465	0.9743
Access to utilities/infrastructure (proportion)			
Electricity	0.0830	0.6042	0.9529
Improved drinking water source	0.3273	0.6105	0.7483
Flush toilet	0.0129	0.0410	0.5322
Characteristics of living residence			
Number of dwelling rooms (*mean*)	2.618	3.010	2.681
Floor of finished materials	0.1800	0.7732	0.9538
Madagascar			
Asset ownership (proportion)			
Car	0.0000	0.0015	0.0646
Motorcycle	0.0000	0.0010	0.1159
Bicycle	0.0468	0.2347	0.4767
Refrigerator	0.0000	0.0000	0.1216
TV	0.0000	0.0059	0.6125

Radio	0.2330	0.5296	0.8661
Mobile phone	0.0000	0.1545	0.8367
Access to utilities/infrastructure (proportion)			
Electricity	0.0000	0.0142	0.6762
Improved drinking water source	0.0000	0.5516	0.8063
Flush toilet	0.0000	0.0132	0.1491
Characteristics of living residence			
Number of dwelling rooms (*mean*)	1.182	1.504	1.980
Floor of finished materials	0.0000	0.1555	0.7163