Eliminating malaria by 2040 among agricultural households in Africa: potential impact on health, labor productivity, education and gender equality [version 1; peer review: 1 approved, 1 approved with reservations]

Derek W. Willis, Nick Hamon

1Center for Research on Environmental Decisions, Columbia University, New York, NY, 10027, USA
2IVCC, Pembroke Place, Liverpool, L3 5QA, UK

Abstract

Background: Ambitious goals have been established to eradicate malaria by the year 2040. Suppressing malaria in rural agricultural communities in sub-Saharan Africa represents one of the greatest challenges to achieving malaria eradication given the poverty and high intensity of malaria transmission in these regions. The objective of this study is to examine how suppressing malaria among smallholder agricultural households in sub-Saharan Africa over the next two decades will affect progress towards achieving the Sustainable Development Goals.

Methods: Using agricultural census data and malaria morbidity data, we developed estimates of the number of malaria cases among smallholder agricultural households for each country in sub-Saharan Africa. Using these estimates as well as additional data from the literature, we analyzed how achieving malaria eradication by 2040 would affect indicators related to four Sustainable Development Goals: health, poverty, education and gender equality.

Results: Our analysis found that achieving malaria eradication would prevent approximately 1 billion malaria cases and thereby decrease the number of lost work-days among agricultural households due to malaria morbidity by approximately 3.8 billion days. Eradicating malaria by 2040 would also increase the number of school days attended by children by 4.5 billion days while also reducing the number of caregiving days by women for malaria cases by approximately 1.9 billion days.

Conclusions: This article analyzed the impact of eradicating malaria among smallholder agricultural households in sub-Saharan Africa in terms of four of the Sustainable Development Goals. Greater recognition of the non-health benefits of achieving malaria eradication could catalyze the agricultural sector to intensify their contributions to eradicating malaria.

Keywords
malaria eradication, agricultural households, Africa, sustainable development goals
Corresponding author: Derek W. Willis (derekwwillis@gmail.com)

Author roles: Willis DW: Conceptualization, Data Curation, Formal Analysis, Methodology, Validation, Writing – Original Draft Preparation; Hamon N: Conceptualization, Funding Acquisition, Supervision, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

Grant information: This work was supported by the Bill and Melinda Gates Foundation (OPP1148615).

Copyright: © 2018 Willis DW and Hamon N. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

How to cite this article: Willis DW and Hamon N. Eliminating malaria by 2040 among agricultural households in Africa: potential impact on health, labor productivity, education and gender equality [version 1; peer review: 1 approved, 1 approved with reservations] Gates Open Research 2018, 2:33 https://doi.org/10.12688/gatesopenres.12843.1

First published: 19 Jul 2018, 2:33 https://doi.org/10.12688/gatesopenres.12843.1
Introduction
An ambitious goal has been established to eradicate malaria by the year 2040 (Gates, n.d.). Suppressing malaria in rural, agricultural communities in sub-Saharan Africa will be one of the greatest challenges in achieving malaria eradication given the poverty and high intensity of malaria transmission in these communities (Kiszewski et al., 2004). Achieving malaria eradication in these communities would not only be a significant public health milestone, but could decrease poverty, increase educational levels of children and improve gender equality.

The Sustainable Development Goals provide a framework for understanding how suppressing malaria would affect health, poverty, education, and gender equality among agricultural households in sub-Saharan Africa (United Nations, 2015). An increased understanding of how malaria eradication would affect progress towards achieving Sustainable Development Goals for agricultural households in Africa could generate increased interest in collaboration efforts between the public health and agricultural sectors.

The objective of this study was to examine how suppressing malaria among smallholder agricultural households in sub-Saharan Africa over the next two decades will affect progress towards achieving the Sustainable Development Goals.

Using agricultural census data and malaria morbidity data, we developed estimates of the number of malaria cases among smallholder agricultural households for each country in sub-Saharan Africa (Willis, 2018). Using these estimates, we analyzed two paths for the malaria burden among smallholder agricultural household from 2018 through 2040. The first path, the status quo path, assumes that the annual malaria morbidity burden among smallholder agricultural households remained at their current levels through 2040. The malaria elimination path assumes that malaria cases among these households decrease annually from 2018 levels to nil in 2040. For each path, we estimated annual indicators related to the following Sustainable Development Goals (SDGs): health, poverty, education and gender equality. These SDGs are summarized in Table 1. By analyzing the difference between corresponding indicators for these two paths, we estimate the impact of eradicating malaria by 2040 on these SDGs. The indicators that we estimated using our dataset (Willis, 2018) are described in Table 2. Figure 1 summarizes our methodology.

Methods
Status Quo Path versus Elimination Path
Our methodology enables us to compare our selected indicators for the SDGs for the Status Quo Path and Malaria Elimination Path. The Status Quo Path refers to the indicators that would occur if the annual number of malaria cases in each country in sub-Saharan Africa remained at their 2018 levels through 2040. The Malaria Elimination Path is the counterfactual case for the corresponding indicators from 2018 through 2040 if the annual number of malaria cases in each country decreased from the 2018 levels to nil in 2040.

We compare the selected SDG indicators from the Status Quo Path and Malaria Elimination Path for two time periods.

<table>
<thead>
<tr>
<th>Goal</th>
<th>Target for 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>#1: No poverty</strong></td>
<td>“By 2030, eradicate extreme poverty for all people everywhere, measured as people living on less than $1.90 a day” (United Nations)</td>
</tr>
<tr>
<td><strong>#2: Zero hunger</strong></td>
<td>“By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round” (United Nations)</td>
</tr>
<tr>
<td></td>
<td>“By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons” (United Nations)</td>
</tr>
<tr>
<td><strong>#3: Good health and well-being</strong></td>
<td>“By 2030, reduce the global maternal mortality ratio to less than 70 per 100,000 live births” (United Nations)</td>
</tr>
<tr>
<td></td>
<td>“By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births” (United Nations)</td>
</tr>
<tr>
<td><strong>#4: Quality education</strong></td>
<td>“By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and Goal-4 effective learning outcomes” (United Nations)</td>
</tr>
<tr>
<td><strong>#5: Gender equality</strong></td>
<td>“Adopt and strengthen sound policies and enforceable legislation for the promotion of gender equality and the empowerment of all women and girls at all levels” (United Nations)</td>
</tr>
<tr>
<td><strong>#10: Reduced inequalities</strong></td>
<td>“By 2030, progressively achieve and sustain income growth of the bottom 40 percent of the population at a rate higher than the national average” (United Nations)</td>
</tr>
</tbody>
</table>
Table 2. Indicators for evaluating impact of suppressing malaria among agricultural households on the relevant Sustainable Development Goals.

<table>
<thead>
<tr>
<th>Goal</th>
<th>Indicator (only agricultural households in Sub-Saharan Africa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1: No poverty</td>
<td>Lost work-days from malaria cases among agricultural households</td>
</tr>
<tr>
<td>#3: Good health and well-being</td>
<td>Malaria cases among agricultural households</td>
</tr>
<tr>
<td>#4: Quality education</td>
<td>No. lost school days by all children due to malaria cases among agricultural households</td>
</tr>
<tr>
<td>#5: Gender equality</td>
<td>No. lost school days by girls due to malaria cases among agricultural households No. of caregiving days by women due to malaria cases among agricultural households</td>
</tr>
</tbody>
</table>

![Figure 1: Methodology for Estimating Impact of Eliminating Malaria on Sustainable Development Goals](image)

The first time period, from 2018 to 2030, corresponds to the target year of 2030 for achieving the SDGs as well as the final year of the ‘Global Technical Strategy for Malaria’ (World Health Organization, 2015). The ‘Global Technical Strategy for Malaria’ has established a goal of suppressing the incidence of malaria cases by 90 percent by 2030 (relative to 2015 levels) (World Health Organization, 2015).

The second time period, from 2018 to 2040, corresponds to the goal of eradicating malaria by 2040 (“Malaria No More | From Aspiration to Action” n.d.).

Three scenarios: most conservative, base case and least conservative
A range of parameter values could be used to develop and analyze our dataset (Willis, 2018) in order to estimate the impact of eliminating malaria on our indicators. Given this uncertainty, we use three different scenarios for developing and analyzing our dataset: the most conservative scenario, the base case scenario, and the least conservative scenario.

Our most conservative scenario represents our parameter estimates which are associated with a lower impact of suppressing malaria.
on the indicators. The least conservative scenario is our set of parameter values associated with the largest impact of suppressing malaria on the indicators. An intermediate set of parameter values are modeled in our base case scenario.

**Detailed summary of methodology**

Here, we describe each step for developing and analyzing our dataset in more detail.

**Definition of smallholder agricultural households**

We will define agricultural households using the same standards that have been used in agricultural censuses of countries in sub-Saharan Africa. The following definition in Ethiopia’s agricultural census in 2010 is representative of the definitions used in most agricultural censuses conducted in Africa:

> A household is considered an agricultural household when at least one member of the household is engaged in growing crops and/or raising livestock in private or in combination with others (Federal Democratic Republic, 2010/2011).

We defined smallholder agricultural households in sub-Saharan Africa as agricultural households that farm areas of 10 hectares or less.

**Annual estimates of population of smallholder agricultural households in sub-Saharan Africa**

Our analysis included only countries in sub-Saharan Africa in which more than half of the country experienced malaria transmission. We therefore excluded Namibia and South Africa from our analysis and focused on the following countries: Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Republic of Congo, Democratic Republic of Congo, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Côte d’Ivoire, Kenya, Liberia, Madagascar, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe.

We use several steps to develop our estimates of the number of smallholder farmers in each country in 2018 as these data are not available from existing datasets.

First, we developed estimates of the total number of farms in 2018 for each country using a study published in 2016 that includes agricultural census data from most countries in sub-Saharan Africa (Lowder et al., 2016). Using these agricultural census data, we estimated that there are approximately 67 million agricultural households in the 35 countries that we are targeting for this study. Agricultural census data were not available for any year for Equatorial Guinea and South Sudan. We estimated the total number of agricultural households Equatorial Guinea and South Sudan for 2018 using the proportion of smallholder agricultural households relative to the total population of neighboring countries.

The next step in developing our dataset (Willis, 2018) was estimating the number of smallholder agricultural households among the total number of agricultural households estimated in the first step. Data for the number of smallholder agricultural households in each country were not available for all of our targeted countries in sub-Saharan Africa. We therefore estimated that 75% of all agricultural households in a country were smallholder households. This estimate is consistent with smallholder household data that were available from Uganda where there were 1,251,179 smallholder households in 1991, out of a total number of 1,704,721 agricultural households in the entire country for that year (Lowder et al., 2016).

We would expect that these estimates for the number of smallholder agricultural households for the sub-Saharan African countries in our study to represent lower-bound estimates as some of the estimates rely on agricultural census data from the 1980s and 1990s (Lowder et al., 2016).

**Annual estimates of total population in agricultural households per country from 2018 to 2040**

Next, we developed annual estimates of the population of smallholder agricultural households in each of the 35 sub-Saharan African countries from 2018 through 2040 as these population estimates were not available in the literature.

We assumed that the number of agricultural households in 2018 remained the same through 2040. Although we would expect the overall population growth rate of sub-Saharan African countries to be around 2.16% through 2040 (World Bank, 2018), the population in rural areas of Africa is not expected to grow at the same rate (“2018 Revision of World Urbanization Prospects” 2018). By contrast, sub-Saharan Africa will experience high urban population growth through 2040:

> Sub-Saharan Africa (SSA) is often is often regarded as the world’s fastest urbanizing region. Urban areas currently contain 472 million people, and will double over the next 25 years. The global share of African urban residents is projected to grow from 11.3 percent in 2010 to 20.2 percent by 2050 (Saghir, 2018).

We assumed that, on average, there are six individuals in each agricultural household. This estimate was based on the number of individuals per household in a recent study of malaria’s impact on harvest values in Zambia (Fink & Masiye, 2015). Estimates of the annual population of smallholder agricultural households for each country are calculated by multiplying six times the annual number of smallholder agricultural households.

**Annual estimates of number of malaria cases among agricultural households per country from 2018 to 2040 - Status Quo Path**

We use the term Status Quo Path to refer to the number of malaria cases in each sub-Saharan African country from 2018 through 2040 if the current anti-malaria programs being implemented in those countries remain unchanged during that period.

We use three different approaches (i.e., most conservative scenario, base case scenario, least conservative scenario) for estimating the Status Quo Path for the annual number of malaria cases
among agricultural households per country from 2018 through 2040.

**Most conservative scenario.** For our most conservative scenario, we estimated the annual number of malaria cases among agricultural household per country by using the total number of malaria cases per country reported in the World Malaria Report for 2017 (WHO, 2017). We divided the total number of malaria cases in a country in 2016 by that country’s total population in 2016 in order to calculate the number of malaria cases per person in 2016. We assumed that that estimate of the number of malaria cases per person in 2016 is the same as the number of malaria cases per person in 2018. By multiplying the number of malaria cases per person in 2018 by the total population of smallholder agricultural households in 2018, we estimated the number of malaria cases among agricultural households in 2018.

For the Status Quo Path, we assumed that the number of malaria cases among these households in a country in 2018 remained unchanged for the subsequent years through 2040. This approach to estimating the number of malaria cases among smallholder households assumed that the malaria risk experienced by agricultural households is the same as the malaria risk of non-agricultural households.

There are two reasons why this approach to estimating the number of malaria cases was conservative and will likely underestimate the actual annual number of malaria cases in each country. First, agricultural households will be primarily in rural areas and the malaria risk of households in rural areas will likely be significantly greater than the risk of households in urban areas. Therefore, assuming malaria risk is the same among all households will underestimate the number of malaria cases experienced by households in rural areas. Second, a significant proportion of malaria cases that actually occur in a country are undiagnosed and therefore not included in official estimates of the number of malaria cases in a country (World Malaria Day: Which Countries Are the Hardest Hit? Get the Full Data, 2012; Roca-Feltrer et al., 2008).

**Base case scenario.** To account for the potential number of malaria cases that are unreported, our base case scenario assumes that approximately half of the actual number of malaria cases that occur among agricultural households are unreported. We therefore multiply the annual number of malaria cases estimated under the most conservative scenario by two in order to derive annual estimates for each country for this scenario. This approach of multiplying the annual number of malaria cases by two is justified based on a statement in 2016 by Dr. Richard Cibulskis of the WHO’s Global Malaria Programme that approximately 90 percent of malaria cases globally are not reported (World Malaria Day: Which Countries Are the Hardest Hit? Get the Full Data, 2012)

**Least conservative scenario.** For estimates of the annual number of malaria cases under our least conservative scenario, we assumed that only one third of the actual number of malaria cases that occur among agricultural households are reported. Accordingly, we multiply the annual number of malaria cases from the most conservative scenario by three in order to estimate the annual number of malaria cases for the least conservative scenario.

**Annual estimates of number of malaria cases among agricultural households per country from 2018 to 2040 - Malaria Elimination Path**

For the malaria elimination path, we used the same estimates for the number of malaria cases in 2018 for each scenario from the status quo path. However, we assumed the annual number of malaria cases for each scenario decreased to zero in 2040.

**Annual estimates of number of lost work-days due to malaria cases among agricultural households per country from 2018 to 2040 - Status Quo Path and Malaria Elimination Path**

In order to estimate the potential impact of eliminating malaria among agricultural households on poverty we use the number of lost work-days due to malaria cases as an indicator.

Studies of the number of lost work-days due to a malaria case among individuals in an agricultural household yield a wide range of values. Most studies estimated the number of lost work-days by adults in sub-Saharan Africa due to a malaria case a ranging from 2 to 6 days (Asenso-Okyere & Dzator, 1997; Attanayake et al., 2000; Gazin et al., 1988; Guiguemé et al., 1997; Larochelle & Dalton, 2005; Leighton & Foster, 1993; Nur & Mahran, 1988; Organization & Espd, 2005; Sauerborn et al., 1991). We therefore used values within this range in our scenarios in order to examine the sensitivity of the model results to these values.

**Most conservative scenario.** For our analysis using our most conservative scenario, we assumed that the annual number of work-days lost due to a malaria case was two days.

**Base case scenario.** The base case scenario assumed that the annual number of work-days lost due to a malaria case was four days.

**Least conservative scenario.** We assumed that six work-days were lost per malaria case for our least conservative scenario.

**Annual estimates of missed school days due to malaria cases among agricultural households per country from 2018 to 2040 - Status Quo Path and Malaria Elimination Path**

Our indicator for the impact of malaria cases on the SDG of improving education was the number of school days missed due to malaria. We assumed that children experienced 90 percent of the annual number of malaria cases among agricultural households in each country and that the number of missed school days by children per malaria case varied from 4 to 8 days (Brooker et al., 2000; Bundy et al., 2000; Chima et al., 2003; Chuma et al., 2010; Konradsen et al., 1997; Leighton & Foster, 1993 Sachs & Malaney, 2002).
Most conservative scenario. For our most conservative scenario, we assumed that the number of school days missed per case of malaria was four days.

Base case scenario. We assumed that six school days were missed due to each malaria case for our base case scenario.

Least conservative scenario. Our least conservative scenario assumed that eight school days were missed per malaria case.

Annual estimates of missed school days by girls due to malaria cases and caregiving days by women for malaria cases
The two indicators we used to estimate malaria’s impact on gender equality are missed school days by girls due to malaria cases and the number of caregiving days by women for malaria cases among children in their household.

We estimated the number of malaria cases among girls by assuming that half of all malaria cases among children are experienced by girls. We used the same number of missed school days per malaria case for each scenario as described for the previous indicator.

Most studies of the number of caregiving days provided by women for malaria cases in the households estimated the number of days as ranging from 1 to 4 days (Asenso-Okyere & Dzator, 1997; Ettling et al., 1994; Leighton & Foster, 1993; Nur, 1993).

Most conservative scenario. Our most conservative scenario assumed that a woman spent 1.5 days providing care for each child’s case of malaria.

Base case scenario. We assumed that 2.5 caregiving days were provided for each child’s case of malaria by a woman in the household.

Least conservative scenario. Our least conservative scenario assumed that 3.5 days were spent by a woman providing care for each child’s case of malaria.

Summary of parameter values for each scenario
The parameter values used in each scenario are summarized in Table 3.

Results
In this section, we analyzed the dataset we developed (Willis, 2018) in order to examine how eliminating malaria among smallholder agricultural households in sub-Saharan Africa by 2040 would potentially affect indicators related to four of the SDGs.

As described in the Methods section, our analysis focused on the following five indicators for agricultural households in 35 countries in sub-Saharan Africa: number of malaria cases, number of lost work-days due to malaria cases, number of lost school days by children due to malaria cases, number of lost school days by girls due to malaria cases and number of caregiving days by women due to malaria cases.

Population of smallholder agricultural households in sub-Saharan Africa
Our analysis of the agricultural census data for the countries included in our study found that there were approximately 53 million smallholder agricultural households in 2018 out of a total number of approximately 70 million agricultural households. Based on our estimate of 6 people per household, the total population of smallholder agricultural households in 2018 was approximately 316 million.

2018 to 2030: Impact of Malaria Elimination Path on SDGs
Table 4 summarizes the impact of suppressing malaria among smallholder agricultural households from 2018 to 2030. We analyze this time period due to the target year for achieving the SDGs being 2030.

Malaria cases among smallholder agricultural households.
Under our base case scenario, there would be approximately 780 million malaria cases among smallholder agricultural households from 2018 through 2030 if malaria elimination was achieved in 2040. By contrast, approximately 1.1 billion malaria cases would occur over that 12-year time period if the status quo was maintained. As a result, approximately 300 million malaria cases would be prevented from 2018 through 2030 by pursuing the path to eradication by 2040.

A lower bound for the number of malaria cases prevented by pursuing eradication can be estimated with the most conservative scenario (195 million) while an upper bound is provided by the least conservative scenario (389 million).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Most conservative scenario</th>
<th>Intermediate Scenario</th>
<th>Least conservative scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaria cases among agric. HHs for 2018</td>
<td>(Total No. malaria cases per country / total population per country) × pop. of agric. HHs</td>
<td>1.5 × most conservative scenario</td>
<td>2 × most conservative scenario</td>
</tr>
<tr>
<td>No. lost work-days per malaria case</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>No. missed school days per child for each malaria case</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>No. caregiving days by women for each malaria case</td>
<td>1.5</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>---------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>#1: No Poverty</td>
<td>No. lost work-days from malaria cases among agric. HHs</td>
<td>1,425,158,888</td>
<td>1,036,479,191</td>
</tr>
<tr>
<td>#3: Good Health &amp; Well-being</td>
<td>No. malaria cases among agric. HHs</td>
<td>712,579,444</td>
<td>518,239,596</td>
</tr>
<tr>
<td>#4: Quality Education</td>
<td>No. lost school days by children due to malaria cases among agric. HHs</td>
<td>2,280,254,221</td>
<td>1,658,366,706</td>
</tr>
<tr>
<td>#5: Gender equality</td>
<td>No. lost school days by girls due to malaria cases among agric. HHs</td>
<td>1,140,127,110</td>
<td>829,183,353</td>
</tr>
<tr>
<td>#5: Gender equality</td>
<td>No. caregiving days by women due to malaria cases among agric. HHs</td>
<td>855,095,333</td>
<td>621,887,515</td>
</tr>
</tbody>
</table>

HH, household.
**Work-days among smallholder agricultural households.** The base case scenario estimate for the number of additional work-days from 2018 to 2030 by suppressing malaria is approximately 1.2 billion days. The lower bound for this estimate is 390 million work-days from our most conservative scenario analysis and the upper bound estimate is 2.3 billion work-days.

**School days among children in smallholder agricultural households.** There would be approximately 1.4 billion additional school days by children of smallholder agricultural households if malaria was suppressed from 2018 to 2030. Our most conservative scenario analysis produces a lower bound estimate of 620 million additional school days while the upper bound estimate was approximately 2.5 billion school days.

**School days by girls in smallholder agricultural households.** If the analysis of lost school days is limited to only girls, the number of additional school days from 2018 to 2030 would be approximately 700 million school days.

**Caregiving days by women in smallholder agricultural households.** With our base case scenario analysis, there would be a reduction in the number of caregiving days by women for children with malaria of approximately 580 million days. The lower bound for this estimate is 230 million caregiving days while the upper bound is 1 billion school days.

**2018 to 2040: Impact of Malaria Elimination Path on SDGs**

In Table 5, we present the results of our analysis of how eliminating malaria would affect our SDG indicators from 2018 through 2040.

**Malaria cases among smallholder agricultural households.** Approximately 950 million malaria cases would be prevented among smallholder agricultural households from 2018 through 2040 based on our base case scenario analysis. The lower bound of this estimate of the number of malaria cases prevented is 630 million, while the upper bound estimate is approximately 1.3 billion.

**Work-days among smallholder agricultural households.** According to our base case analysis, there would be approximately 3.8 billion additional work-days among smallholder agricultural households if malaria was eliminated by 2040 relative to the status quo path. Our most conservative scenario analysis generates an estimate of 1.3 billion work-days prevented for the lower bound and our least conservative scenario estimates the number of work-days prevented as 7.5 billion.

**School days among children in smallholder agricultural households.** Approximately 4.5 billion school days would be gained from 2018 through 2040 by achieving malaria elimination in 2040. The lower bound estimate for this analysis is 2 billion school days while the upper bound estimate is 8 billion school days.

**School days by girls in smallholder agricultural households.** The number of additional school days of girls from 2018 through 2040 would be approximately 2.25 billion school days, with a lower bound estimate of 1 billion school days and an upper bound estimate of 4 billion school days.

**Caregiving days by women in smallholder agricultural households.** The number of caregiving days by women reduced from 2018 to 2040 would be 1.9 billion days according to our base case analysis. Our most conservative scenario generates a lower bound estimate of 750 million caregiving days reduced while the upper bound estimate is approximately 3.5 billion caregiving days decreased.

**Discussion**

To our knowledge, we have developed the first estimates of the number of malaria cases of agricultural households in sub-Saharan Africa and the potential impact of suppressing malaria among these households on four Sustainable Development Goals.

The results of this analysis suggest that the path to achieving malaria eradication by 2040 could yield a compounding positive effect on smallholder agricultural households in sub-Saharan Africa by significantly increasing the number of days worked and school days attended.

We would expect that our estimates of the impact of suppressing malaria on the selected indicators for the SDGs are conservative. The larger the number of smallholder agricultural households in sub-Saharan Africa in 2018, the larger the number of malaria cases among those households in 2018 and, therefore, the larger the resulting impact of eliminating malaria among these households by 2040 on the SDGs. As indicated in the Methods section, our estimates for the number of agricultural households in sub-Saharan Africa are conservative, which would imply that our estimates of the impact of suppressing malaria among these households on the indicators for the Sustainable Development Goals are also conservative.

**Limitations of this research**

One limitation of this study is our methodology for estimating the number of malaria cases among smallholder agricultural households in sub-Saharan Africa. A more rigorous means of generating sub-national estimates of malaria cases among these households would facilitate better estimates of the impact of suppressing malaria on the SDGs.

**Policy implications**

The proportion of farmers in sub-Saharan Africa relative to its total population in 2018 is similar to the proportion of farmers in the United States in 1916. In 1916, the farm population of the United States was approximately 32 percent of the country’s total population (AP n.d.). Our analysis suggests that about 32% of sub-Saharan Africa’s total population are smallholder farmers as we estimated that there are 315 million smallholder farmers out of a total population in sub-Saharan Africa of approximately 1 billion (World Bank, 2018).

Malaria was endemic in the southern part of the United States until the 1930s but declined steadily throughout the 1940s (Sledge & Mohler, 2013). One factor that contributed to malaria being eliminated in the United States in 1949 was economic...
Table 5. Impact of malaria elimination path on Sustainable Development Goals (2018 to 2040).

<table>
<thead>
<tr>
<th>Sustainable Development Goal</th>
<th>Indicator</th>
<th>Status Quo</th>
<th>Elimination Path</th>
<th>Impact by 2040</th>
<th>Status Quo</th>
<th>Elimination Path</th>
<th>Impact by 2040</th>
<th>Status Quo</th>
<th>Elimination Path</th>
<th>Impact by 2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1: No Poverty</td>
<td>No. lost work-days from malaria cases among agric. HHs</td>
<td>2,521,434,956</td>
<td>1,260,717,478</td>
<td>-1,260,717,478</td>
<td>7,564,304,868</td>
<td>3,782,152,434</td>
<td>-3,782,152,434</td>
<td>15,128,609,735</td>
<td>7,564,304,868</td>
<td>-7,564,304,868</td>
</tr>
<tr>
<td>#3: Good Health &amp; Well-being</td>
<td>No. malaria cases among agric. HHs</td>
<td>1,260,717,478</td>
<td>630,358,739</td>
<td>-630,358,739</td>
<td>1,891,076,217</td>
<td>945,538,108</td>
<td>-945,538,108</td>
<td>2,521,434,956</td>
<td>1,260,717,478</td>
<td>-1,260,717,478</td>
</tr>
<tr>
<td>#4: Quality Education</td>
<td>No. lost school days by children due to malaria cases among agric. HHs</td>
<td>4,034,295,929</td>
<td>2,017,147,965</td>
<td>-2,017,147,965</td>
<td>9,077,165,841</td>
<td>4,538,582,921</td>
<td>-4,538,582,921</td>
<td>16,137,183,718</td>
<td>8,068,591,859</td>
<td>-8,068,591,859</td>
</tr>
<tr>
<td>#5: Gender equality</td>
<td>No. lost school days by girls due to malaria cases among agric. HHs</td>
<td>2,017,147,965</td>
<td>1,008,573,982</td>
<td>-1,008,573,982</td>
<td>4,538,582,921</td>
<td>2,269,291,460</td>
<td>-2,269,291,460</td>
<td>8,068,591,859</td>
<td>4,034,295,929</td>
<td>-4,034,295,929</td>
</tr>
<tr>
<td>#5: Gender equality</td>
<td>No. caregiving days by women due to malaria cases among agric. HHs</td>
<td>1,512,860,974</td>
<td>756,430,487</td>
<td>-756,430,487</td>
<td>3,782,152,434</td>
<td>1,891,076,217</td>
<td>-1,891,076,217</td>
<td>7,060,017,877</td>
<td>3,530,008,938</td>
<td>-3,530,008,938</td>
</tr>
</tbody>
</table>

HH, household.
development and housing improvements in the US South (Humphreys, 1998)

Our study represents the first attempt to quantify the impact that eliminating malaria would have on smallholder farmers across sub-Saharan Africa in terms of work-days missed, school days missed and caregiving days provided.

The potential impact of eliminating malaria on the welfare of smallholder farmers will not be limited to these indicators. Fewer work-days missed could contribute to higher incomes for smallholder farmers, which could lead to investments in improved housing and, as a result, fewer cases of malaria. An increase in the incomes of smallholder farmers could also lead to increased investments by farmers in agricultural inputs to improve crop yields.

Achieving malaria eradication by 2040, and the resulting positive effect on the Sustainable Development Goals, will require that vector control interventions continue to play a key role in anti-malaria programs. Vector control has been shown to be the most effective intervention for reducing the malaria burden (Bhatt et al., 2015). Long-lasting insecticide-treated bed nets (LLINs) and indoor residual spraying (IRS) were responsible for 78% of the reduction in malaria cases between 2000 and 2015 (Bhatt et al., 2015). Most successful vector control interventions use insecticides that have been repurposed from modern agriculture. The impact of these interventions is being compromised by the development of resistance to the classes of insecticides currently used in vector control.

Investments by agricultural chemical companies in developing and delivering novel vector control tools will likely be essential to achieving malaria eradication by 2040. These investments will not only play a key role in improving the health of smallholder farmers in Africa but could significantly accelerate growth in the incomes of these farmers as well by increasing their productivity.

Future work
In order to better understand how investments by agricultural chemical companies in vector control tools will affect smallholder farmers over the next 20 years, additional research is needed in three areas. First, researchers need to examine how suppressing malaria risk among smallholder farmers in Africa affects their decisions of which crops to plant. Second, analyses are needed of the relationship between an increase in the income of smallholder farmers and any change in their malaria risk. There is some evidence that higher farmer incomes leads to reduced malaria risk (Jumba & Lindsay, 2001) and increased investment in housing (Sachs, 2018), but additional research is needed. Finally, researchers should examine the relationship between higher incomes of smallholder farmers and farmers’ decisions of how much to invest in agricultural inputs.

Data availability
The dataset for this research has been deposited in CSV format with the Harvard Dataverse repository: https://doi.org/10.7910/DVN/2F3J3XT (Willis, 2018). Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

Competing interests
No competing interests were disclosed.

Grant information
This work was supported by the Bill and Melinda Gates Foundation (OPP1148615).

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Acknowledgments
The authors wish to thank Ma Victoria Acuña for her excellent research assistance with this project.

References


PubMed Abstract | Publisher Full Text


PubMed Abstract | Publisher Full Text


PubMed Abstract | Publisher Full Text


PubMed Abstract | Publisher Full Text | Free Full Text


PubMed Abstract

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998

Publisher Full Text

Bhatt et al., 2015

Trop Med Int Health.

Publisher Full Text

Humphreys, 1998
Open Peer Review

Current Peer Review Status: ✔️ ✂️

Version 1

Reviewer Report 31 July 2018

https://doi.org/10.21956/gatesopenres.13924.r26567

© 2018 Njau J. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Joseph Njau
School of Medicine, University of California, San Francisco, San Francisco, CA, USA

The objective of this study was to examine how suppressing malaria among smallholder agricultural households in SSA over the next two decades will affect progress towards achieving sustainable Development Goals (SDGs). The study is innovative and uses new data source that is usually not often used in traditional malaria studies. The study also aims to break new grounds in malaria analyses by linking malaria elimination with achievement of UN SDGs.

However, this study may not be as reproducible or generalizable because of the following limitations:

1) Reliability of the data. In most cases, a lot of the data had to be imputed with a lot of assumptions made to achieve study goals.
2) Some of the assumptions made are excessively broad and may be unrealistic. For instance, taking a single year malaria infection rate to project all future malaria infections until 2040 is unrealistic because we already do know that there are a lot of malaria infection fluctuations. We have seen low infections at the beginning of this decade, we have had high infection rates in the last two years because of increased rain intensities etc. So, it may not be appropriate to use single year estimates to project all future malaria infection rates until 2040
   - I would suggest using other modeling/statistical approaches like Monte Carlo simulations based on up to five years of past malaria infection rates.
   - Use PERT distribution to project different malaria infection rates over time and model the impact on malaria suppression based on such numbers.
3) The study may have been too ambitious in terms of number of countries included in the analysis. One could have started small with countries that had the most reliable data and get precise estimates from those countries first before expanding to include countries with less reliable data.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Partly
Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

**Competing Interests:** No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 20 July 2018

https://doi.org/10.21956/gatesopenres.13924.r26577

© 2018 Omotayo A. This is an open access peer review report distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abiodun Olusola Omotayo

Faculty of Natural and Agricultural Sciences, North-West University (NWU), Potchefstroom, South Africa

The work has been identified to be a good research work towards a United Nation’s sustainable goals.

The authors should have a second look at the work and revise accordingly by adding the suggested articles and look critically into the few comments identified.

The authors should ensure the paper cite properly as there are still facts mentioned with no references.

The work should go for technical English editing. Also, perfect the formatting to the dictates of the Journals authors’ guide.

The methodology is though not so robust but the beauty of the work has been properly showcased and articulated through the excellent scholarly discussion of the subject matter.

Further comments can be found in an annotated copy of the article, accessed [here](https://doi.org/10.21956/gatesopenres.13924.r26577).

**Is the work clearly and accurately presented and does it cite the current literature?**
Yes
Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Agricultural environment and health economist

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.