

Scaling Up Malaria Control in Africa: An Economic and Epidemiological Assessment

Awash Teklehaimanot,* Gordon C. McCord, and Jeffrey D. Sachs

The Earth Institute at Columbia University, Columbia University, New York, New York

Abstract. This paper estimates the number of people at risk of contracting malaria in Africa using GIS methods and the disease's epidemiologic characteristics. It then estimates yearly costs of covering the population at risk with the package of interventions (differing by level of malaria endemicity and differing for rural and urban populations) for malaria as recommended by the UN Millennium Project. These projected costs are calculated assuming a ramp-up of coverage to full coverage by 2008, and then projected out through 2015 to give a year-by-year cost of meeting the Millennium Development Goal for reducing the burden of malaria by 75%. We conclude that the cost of comprehensive malaria control for Africa is US\$3.0 billion per year on average, or around US\$4.02 per African at risk.

INTRODUCTION

The burden of malaria in Africa continues to be extremely high, despite the existence of effective interventions to curb the mortality and morbidity of the disease. Every year, up to 3 million people die of malaria on the continent.¹ The Millennium Development Goals set in 2000 recognize that malaria must be controlled if Africa is to escape from the cycle of extreme poverty and disease. The MDG on malaria is to “Have halted by 2015 and begun to reverse the incidence of malaria,” which has been made more specific by the UN Millennium Project's working group on malaria as “Reduce malaria morbidity and mortality by 75 percent by 2015 from the 2005 baseline level.” In January 2005, the working group on malaria recommended that countries where malaria is rife should use an integrated package of preventive and treatment methods to achieve this goal.² The project also recommended that insecticide-treated mosquito bed nets and effective malaria drugs be given away free of charge, a move endorsed by UN Secretary-General Kofi Annan in March 2005 and by heads of state at the UN World Summit in September 2005.

There are existing, effective methods to control malaria: prevent people from being bitten by mosquitoes, by using insecticide-treated bed nets and insecticide spray applications, treat those who get infected with effective drugs such as artemisinin-based combination therapies (ACTs), promote health education and communication, and conduct monitoring and evaluation. This paper estimates the number of people at risk of contracting malaria in Africa using GIS methods, and then estimates the yearly costs of covering the population at risk with the package of interventions recommended by the UN Millennium Project.

DERIVATION OF POPULATION AT RISK

Due to lack of adequate data collection in Africa's health system, there is incomplete information on the morbidity and mortality associated with malaria.³ The WHO Global Burden of Disease program estimates burden in Africa through “active” case-detection studies of populations living under different transmission intensity risks, which is subject to under-detection. Several alternative studies have estimated population at risk using other methods, including estimates based on

national surveys,⁴ estimates based on climate suitability for malaria transmission,^{5,6} and estimates based on maps of the geographic extent of malaria in a Geographic Information System (GIS).⁷

We follow the GIS-based strategy by overlaying the following maps: a high-resolution (30 arc-seconds) map of the 2005 human population;⁸ a map of country boundaries, the most recent (2002) map of the extent malaria of risk⁹ (Figure 1); a map of malaria-endemicity levels constructed in 1968¹⁰ (Figure 2); and a map of the extent of urban areas.⁸ The latter 4 maps were rasterized to the same 30 arc-second cell size. Population sums were then calculated by country for the following categories: total population within the malaria risk zone, population within a malaria risk zone *and* within an urban zone, population within a malaria risk zone *and* within a zone of unstable malaria transmission (either hypoendemic or mesoendemic zones in the endemicity map), and population within a malaria risk zone, an urban zone, and a zone of unstable transmission. (Note that areas on the 1968 endemicity map but that are outside the area of 2002 malaria risk are considered to no longer have malaria and are ignored). The resulting estimate for population at risk of malaria in Africa in 2006 is 672 million people, of which 485 million are in rural areas (see Table 1). Finally, we used the UN Population Division's median forecast of projected population to calculate a population growth rate for each country and used it to estimate the population in each country in the above categories for every year between 2006 and 2015. This now allows us to calculate the cost of each intervention, by country and by year, based on the urban and rural population at risk, in stable and unstable malaria transmission areas.

DESCRIPTION OF COMPREHENSIVE INTERVENTIONS

The interventions included in this costing exercise encompass most of the key interventions recommended by the UN Millennium Project, and many details of the costing follow those of the report of the Working Group on Malaria.² For prevention of disease, they include long-lasting insecticidal bed nets (LLINs), indoor residual spraying (IRS) in unstable transmission areas, training of community health workers, and cost of an information, education, and communication program. For enhanced diagnosis and treatment, they include microscopy, rapid diagnostic tests, effective drugs such as artemisinin-combination therapies (ACTs) for uncomplicated malaria, and treatment of severe malaria. Finally, the costing

* Address correspondence to Awash Teklehaimanot, 2910 Broadway MC 3277 Hogan Hall, 110B New York, NY 10025. E-mail: awash@ei.columbia.edu

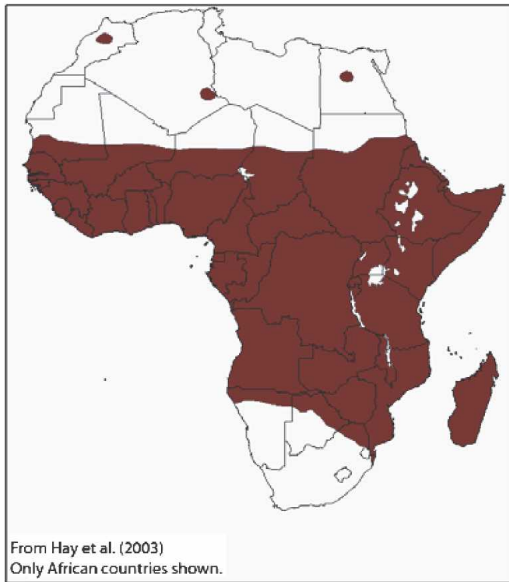


FIGURE 1. Extent of malaria risk in Africa, 2002.

includes resources for monitoring and evaluation and for the overhead costs of a global push on malaria control. Below are the assumptions made for each intervention:

- **Long-lasting insecticidal nets (LLINs):** Following the UN Millennium Project's recommendation, we calculate the cost of complete coverage of LLINs for the population at risk by the end of 2008, with a ramp-up of coverage during 2006, 2007, and 2008. Note that this is a more ambitious target than other costing exercises; the efficacy of LLINs and the mass action effect implies that the entire population, and not just children and pregnant women, should be targeted by LLIN distribution programs.¹¹ We assume that one net is needed for every two people at risk. The cost of

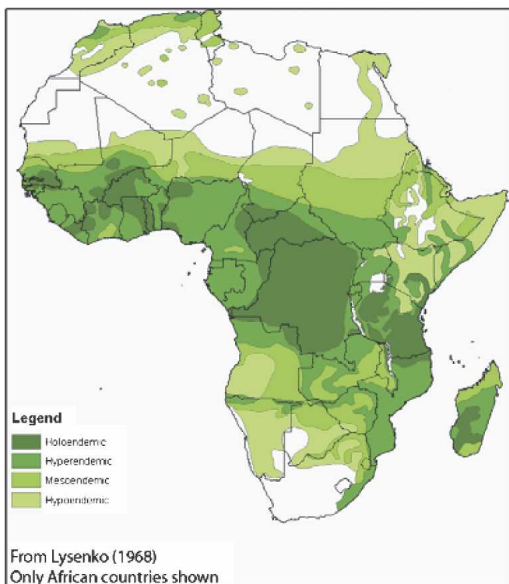


FIGURE 2. Endemicity levels in Africa.

LLINs is around \$5, with an additional \$2 estimated cost of storage and distribution, and the net needs to be replaced after 5 years (as is the case with Olyset nets).¹² Note that long-lasting nets do not need to be re-impregnated with insecticide during their 5-year lifespan.

- **Indoor residual spraying (IRS):** Selective vector control (including IRS) was part of the WHO's Global Strategy for Malaria Control, which was adopted by the Ministerial Conference in 1992 and subsequently endorsed by the World Health Assembly (WHA) and the UN General Assembly. The Global Strategy was also taken up by the RBM partnership for the use of selective control in appropriate epidemiologic settings. Recently, the U.S. President's Malaria Initiative (PMI) has also emphasized the benefits of IRS. We have estimated the average annual cost of using IRS against malaria in unstable transmission areas at \$206 million. However, the cost of blanket spraying all malaria-transmission areas is \$1.1 billion or up to \$2 billion, considering that intense transmission areas require > 1 round of spraying per year. Thus blanket coverage with IRS seems prohibitively expensive, especially because intense transmission areas will be scaling up LLIN coverage, and LLINs are easier to distribute, last for up to 5 years, face less complex logistic challenges than IRS, and require fewer human resources. We therefore include costs for IRS in unstable transmission areas only because these areas face higher risks of mortality (note that there are some stable transmission areas of special economic consideration, such as resorts or mining operations, where private-sector budgets will cover the high per capita costs of IRS). We assume that Lysenko's map of endemicity (Figure 2) in Africa continues to represent relative transmission strength in Africa today; unlike other parts of the world, the continent has benefited from few antimalaria interventions. We consider the areas of the 2002 extent of malaria risk that are hypoendemic and mesoendemic in Lysenko's map to be low- and moderate-transmission areas and thus are recommended for IRS. (This area, encompassing much of eastern African, part of southern Africa, and the Sahel countries, is roughly the area that experts describe as having unstable transmission.¹³) By overlaying this area with the population map, we estimate that 149 million people lived in low- and moderate-transmission areas in Africa in 2005. We follow the costing methodology of the UN Millennium Project Working Group on Malaria. Because costs are at the household level, we assume an average of 5 people per household, that each household has $\approx 300 \text{ m}^2$ of surface that needs to be sprayed, that each square meter requires 2.67 g of insecticide (DDT, the insecticide of choice), we add a 10% margin of insecticide, and use a cost of US\$4.3 per kilogram of insecticide (this cost corresponds to DDT). In addition, we cost the labor requirements for IRS. We divide number of households by 360 person-days to obtain the number of spray persons needed. We assume 5 spray persons for each squad, 5 squads for each team and for each technician, and 1 supervisor for 5 teams. Wages were set at US\$10 per day for the spray persons (for 40 days of work plus 6 training days), US\$15 per day for squad chiefs and technicians (both also for 46 days), and US\$20 per day for supervisors (for 18 person-days of work). For field equipment, we include a tent (US\$2000) for each team and each supervisor, and add \$100 per person for all personnel for

TABLE 1
Population at risk in 2006 (millions)

	By endemicity level										
	Total	Urban	Rural	Intensive (holoendemic + hyperendemic)				Unstable (mesoendemic + hypoendemic)			
				By age group				By age group			
				0-4	5-9	10-14	14+	0-4	5-9	10-14	14+
Algeria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Angola	15.60	4.87	10.73	1.23	0.97	0.86	3.54	1.68	1.32	1.17	4.83
Benin	7.58	2.92	4.66	1.29	1.09	0.95	4.25	0.00	0.00	0.00	0.00
Botswana	0.70	0.25	0.45	0.00	0.00	0.00	0.02	0.08	0.08	0.09	0.42
Burkina Faso	13.88	1.75	12.13	2.57	2.12	1.84	7.36	0.00	0.00	0.00	0.00
Burundi	6.55	0.45	6.09	1.16	0.92	0.84	3.63	0.00	0.00	0.00	0.00
Cameroon	16.54	7.09	9.45	2.42	2.18	2.06	9.64	0.04	0.03	0.03	0.14
Central African Republic	4.00	1.51	2.49	0.62	0.56	0.51	2.26	0.01	0.01	0.01	0.03
Chad	9.14	1.85	7.30	1.25	0.99	0.84	3.42	0.51	0.40	0.34	1.40
Comoros	0.62	0.15	0.47	0.10	0.09	0.07	0.36	0.00	0.00	0.00	0.00
Congo	3.70	2.36	1.33	0.69	0.57	0.48	1.95	0.00	0.00	0.00	0.00
Congo, Dem. Rep.	60.13	17.66	42.48	11.76	9.11	7.60	31.66	0.00	0.00	0.00	0.00
Côte d'Ivoire	17.17	6.91	10.26	2.01	1.81	1.70	7.77	0.59	0.53	0.50	2.27
Djibouti	0.59	0.40	0.19	0.00	0.00	0.00	0.00	0.09	0.08	0.07	0.35
Egypt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equatorial Guinea	0.50	0.19	0.31	0.09	0.07	0.06	0.28	0.00	0.00	0.00	0.00
Eritrea	4.70	0.60	4.10	0.06	0.05	0.05	0.20	0.74	0.64	0.55	2.40
Ethiopia	57.86	7.57	50.29	3.98	3.45	3.09	13.26	5.70	4.94	4.43	19.01
Gabon	1.32	0.94	0.37	0.18	0.17	0.17	0.80	0.00	0.00	0.00	0.00
Gambia, The	1.44	0.76	0.69	0.22	0.19	0.17	0.87	0.00	0.00	0.00	0.00
Ghana	21.80	7.64	14.16	3.02	2.76	2.63	13.39	0.00	0.00	0.00	0.00
Guinea	9.18	2.83	6.36	1.54	1.30	1.16	5.18	0.00	0.00	0.00	0.00
Guinea-Bissau	1.37	0.40	0.97	0.27	0.21	0.17	0.72	0.00	0.00	0.00	0.00
Kenya	33.03	6.78	26.25	4.31	3.52	3.08	14.60	1.27	1.04	0.91	4.30
Liberia	3.15	1.15	1.99	0.61	0.48	0.40	1.66	0.00	0.00	0.00	0.00
Libya	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Madagascar	18.70	3.57	15.13	2.38	2.13	1.82	8.12	0.70	0.63	0.54	2.39
Malawi	12.72	2.15	10.57	0.53	0.47	0.40	1.56	1.75	1.56	1.31	5.14
Mali	13.40	3.15	10.25	2.38	1.96	1.65	6.45	0.18	0.15	0.13	0.50
Mauritania	1.30	0.34	0.96	0.00	0.00	0.00	0.01	0.22	0.18	0.15	0.73
Morocco	2.53	0.91	1.62	0.05	0.04	0.04	0.31	0.22	0.21	0.21	1.45
Mozambique	20.25	5.82	14.43	3.20	2.80	2.51	10.90	0.14	0.12	0.11	0.47
Namibia	1.10	0.24	0.87	0.09	0.09	0.09	0.39	0.06	0.06	0.06	0.26
Niger	13.01	2.17	10.85	1.27	1.00	0.80	3.18	1.37	1.08	0.86	3.45
Nigeria	128.29	44.66	83.63	21.51	18.42	16.48	71.76	0.02	0.02	0.02	0.07
Rwanda	8.77	0.59	8.17	1.46	1.22	1.10	4.99	0.00	0.00	0.00	0.00
São Tome and Príncipe	0.15	0.06	0.09	0.02	0.02	0.02	0.09	0.00	0.00	0.00	0.00
Senegal	10.64	4.59	6.06	0.82	0.72	0.66	3.01	0.85	0.75	0.69	3.14
Sierra Leone	5.41	1.69	3.71	0.94	0.74	0.64	3.09	0.00	0.00	0.00	0.00
Somalia	10.38	2.36	8.02	0.86	0.71	0.56	2.68	1.00	0.82	0.65	3.11
South Africa	6.15	1.49	4.67	0.02	0.02	0.02	0.13	0.65	0.64	0.64	4.03
Sudan	33.48	10.21	23.27	0.68	0.62	0.56	2.91	4.08	3.73	3.38	17.53
Swaziland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tanzania, United Republic of	37.17	11.68	25.49	5.33	4.79	4.35	19.77	0.46	0.41	0.37	1.69
Togo	5.28	1.69	3.60	0.86	0.75	0.67	3.00	0.00	0.00	0.00	0.00
Uganda	27.83	3.51	24.32	5.65	4.44	3.63	13.45	0.14	0.11	0.09	0.33
Zambia	11.59	4.12	7.47	1.09	0.95	0.86	3.45	0.90	0.78	0.71	2.85
Zimbabwe	13.05	4.84	8.21	0.61	0.59	0.60	2.77	1.13	1.09	1.12	5.13
All of Africa	671.78	186.85	484.94	89.13	75.11	66.17	288.82	24.58	21.44	19.12	87.42

coveralls, handgloves, goggles, buckets, soaps, etc., and US\$0.06 in forms and stationary for each household sprayed. For the first year (2006), we include the cost of the spray pump and spare parts (US\$500) for each spray person. Finally, we recognize the costs of other logistics, including vehicles to transport equipment and personnel, spare parts and maintenance, fuel and lubricant, and insurance for the spraying team and vehicles. Because the UN Millennium Project Working Group on Malaria estimated costs for these items in Ethiopia based on the number of districts, we cannot replicate the costing in this exercise (as we are only working with at-risk populations in each coun-

try). We therefore totaled these costs (for every year) in the Working Group's exercise and found them to be 30% of the other costs of IRS (which we do model). We therefore added 30% of total IRS costs as an estimate of the cost of logistics.

- **Training community health workers (CHW):** An RBM survey indicated that between 70% and 90% of febrile children are treated at home.² There is therefore an urgent need to treat uncomplicated malaria at the community level, especially given evidence of decreased child mortality among those who see a community health worker (CHW).¹⁴ A number of countries are seeking to improve

coverage by extending health services using CHWs for malaria diagnosis and treatment services. We assume that one CHW is needed per 500 population and that training for malaria control lasts 8 days and costs \$10 per day.

- **Human resource development:** Note that there are other needs in human resource development; the Malaria Working Group indicates that besides CHWs, training of nurses, physicians, entomologists, and malariologists will be needed to guide and implement the program activities. However, these costs are estimated based on the size of the formal health sector (number of hospitals, etc.) and are not estimated based on the size of the population at risk. We approximate the costs based on the methodology of the Working Group on Malaria as follows: we consider the total cost of leadership training for program managers and topping up salaries for medical officers, epidemiologists, entomologists, biologists, health officers, nurses, environmental health workers, and malaria technicians. The estimated costs total \$704 million for Ethiopia from 2005 to 2015. Using our estimate of population at risk, we find that this number of human resource development needs translates into around \$1.00 per person at risk per year, and use the same assumption for all countries in Africa based on population at risk.
- **Microscopy:** We expect that health facilities such as health centers, rural hospitals, and all hospitals in urban areas will use microscopic examination of stained thick and thin blood smears, the gold standard for malaria diagnosis. The Working Group on Malaria estimates the cost of microscopy using the numbers of hospitals and other health centers in a country, which cannot be duplicated in this paper. We therefore estimate the cost of microscopy as we did for topping up salaries. The Working Group on Malaria estimated that the total cost of microscopy for Ethiopia from 2005 to 2015 to be \approx \$29 million. Using our estimates of population at risk, we find that this number is equivalent to \approx \$0.04 per person at risk per year, and we use this number to estimate microscopy costs for all the countries. Note that microscopes can be used for other purposes (TB and other parasitic and bacterial diseases).
- **Rapid diagnostic testing (RDT):** Given that peripheral levels of the health system—particularly rural areas—often cannot meet the laboratory requirements for microscopy, a variety of simple and rapid diagnostic tests have been developed for accurate and reliable malaria diagnosis by community health workers and health facilities. We assume that RDTs should be used only in unstable transmission areas, for all age groups. (In areas of intense transmission, where severe disease and mortality are largely concentrated in children < 5 years of age, malaria should be treated on the basis of clinical suspicion of malaria and not on confirmed diagnosis by RDTs. People older than 5 years of age have a well-developed level of immunity, are at lesser risk of developing severe malaria, and a significant proportion are asymptomatic in the presence of malaria parasites. This group (> 5 years old living in intense transmission areas) constitutes the bulk of the febrile cases in Africa (we estimate \approx 218 million fever episodes) and at the moment will be too expensive to subject every one of them to RDT examination. They should therefore be treated clinically on the basis of seasonality and clinical manifestation of the disease.) We use the UN Population Division's World

Population Prospects' demographic breakdown for every year between 2006 and 2015 to divide our population at risk into groups of age 0–4, 5–9, 10–14, and 14+ years. Under WHO guidelines, the first age group does not require RDT, because in patients below age 5, every fever episode immediately receives malaria treatment due to the possibility of misdiagnosis.¹⁵ Following similar assumptions to the costing done by the UN Millennium Project Working Group on Malaria, the age groups of 5–9 and 10–14 years are assumed to experience 1 fever episode per year, and the 14+ age group experiences 0.5 fever episode per year (these are taken as the average number of fevers from all causes, across all endemicity levels). One RDT kit is needed for each of these fever episodes (again, we restrict ourselves to unstable transmission areas) and costs at US\$0.61 per kit. Note, that we have built into the model a decrease in fever episodes as LLIN coverage increases: we assume that the proportion of the population covered by LLINs has a 50% reduction in fever episodes (measured reduction in morbidity has ranged from 44% to 75%^{16–19}). This decreases the need for RDT as LLIN coverage increases. Moreover, we have assumed that the number of fever episodes for populations living in urban areas is 25% smaller, because transmission tends to be lower in urban areas.

- **Artemisinin-based combination therapies (ACTs):** We again calculated fever episodes for each of the 4 age groups mentioned above (including the 0–4 age group, which we assume experience 2 fever episodes per year). We assume that RDT in unstable transmission areas will reveal that \approx 40% of the fevers are due to malaria and require ACTs (as was assumed by the UN Millennium Project Working Group on Malaria). In intense transmission areas, on the other hand, we assume that 20% of the fever episodes will be examined by microscopy, and these will have a slide positivity rate of 40% (Ethiopia's current slide positivity rate). The 80% of fevers not examined by microscopy all require ACTs. Our total number of fever episodes requiring malaria treatment in 2006 is 395 million, which is within the range of other published estimates. (*The World Malaria Report 2005* (RBM/WHO/UNICEF) estimates between 210 and 300 million clinical cases in Africa. Snow and others⁴ estimate 1.7 billion fever episodes in Africa per year, and find cost of treating 60% of these fevers with ACTs. Snow and others,⁷ meanwhile, estimate 365 million clinical cases in 2002.) We assume that each treatment course can be treated with either artemether–lumefantrine or artesunate–amodiaquine. Artemether–lumefantrine is assumed to cost US\$0.45 for the 0–4 age group, US\$0.90 for the 5–9 age group, US\$1.35 for the 10–14 age group, and US\$1.80 for the 14+ age group.²⁰ Artesunate–amodiaquine is estimated to cost US\$0.23 for the children under 1, \$0.45 for the 1–6 age group, US\$0.80 for the 7–13 age group, and \$1.48 for the 13+ age group (we use RBM's recommended dosages²¹ and averages of prices from Sanofi-Aventis, Ipca, and Cipla²² and adjust to match age groups in our analysis). We use the average of the cost of artemether–lumefantrine and artesunate–amodiaquine. As above, we assume a 50% reduction in fever episodes for the population covered by LLINs and 25% fewer fever episodes among urban populations. For intense transmission areas, this is a 50% reduction in all fevers; for unstable transmission areas, it is a 50% reduction of fevers that needs ACTs, that is, a 50% reduc-

tion of the original 40% of total fevers. ACT production is a bottleneck, as discussed below; but we assume that enough ACTs will be produced to meet need starting in 2008, although for 2006 and 2007 there will be a shortage. We include a US\$0.10 cost of using other drugs (sulfadoxine–pyrimethamine [SP]–amodiaquine combination or SP–chloroquine combination) to treat the fevers that will not be treated with ACTs in 2006 and 2007. It is expected that in a year's time, ACTs such as dihydroartemisinin piperazine will become available, resulting in overall increased production and cost reduction.

- **Management of severe malaria:** We include a rough approximation of management of severe malaria, using the median cost of \$29.50 for managing a severe malaria case as derived by WHO/AFRO.²³ We assume that $\approx 1\%$ of the malaria episodes would progress to severe malaria.²⁴
- **Information, education, and communication:** A program to educate communities and promote behavioral change is an important element in successful malaria reduction. The program should produce information, education, and communication materials targeting health workers, community leaders, and communities; it should use radio spots, television, drama, and other educational media to increase treatment-seeking behavior, compliance, and use of LLINs, target IRS; and organize sensitization and advocacy meetings at district, regional, and national levels. The Working Group on Malaria estimated that the cost of IEC for Ethiopia \$614,000 per year. Using our estimates of population at risk, we find that this number is equivalent to around \$0.011 per person at risk per year, and we use this number to estimate IEC costs for all the countries.
- **Monitoring and evaluation:** Monitoring and evaluation are essential components of malaria control programs to track effectiveness of the interventions over time. Activities involve assessment of routine health services data and periodic community and household surveys to develop process indicators for implementation, and outcome indicators for case management, prevention, and program impact.²⁵ In addition, the effectiveness of antimalarials and insecticides must be monitored. Following the standard practice in programs funded by the Global Fund to fight AIDS, TB and Malaria, we add 7% of costs as monitoring and evaluation.

- **Overhead costs:** Finally, we add 10% of the cost to account for the overhead costs in a global effort to reach full coverage of these malaria interventions by 2008.

Using our estimated population at risk and the costing assumptions above, we arrive at the projected total yearly costs for all of Africa shown in Table 2 and graphed Figure 3.

The most striking fact from these numbers is their modest magnitude. Given that we are talking about a disease that kills ≈ 2 million African children every year, the fact that full coverage of LLINs and ACTs (plus the other interventions) costs only \$3.00 per African (or \$4.02 per person at risk of malaria) is astounding and encouraging.

We examined these numbers in comparison with earlier studies. The UN Millennium Project Working Group on Malaria performed a detailed costing of interventions for Ethiopia, and arrived at an average of US\$238 million per year, which comes to around US\$2.70 per capita per year (compared with \$3.00 in our results above; note that unlike the working group, we include salaries for CHWs, without which our per capita cost is \$2.29). Another costing estimate²⁶ of malaria interventions for Africa results in \$1.7 billion, an equivalent of \approx US\$2.10 per person at risk per year. It is heartening that our GIS-based approach and different costing assumptions produce similar results and corroborate the magnitude of the per capita cost of these interventions.

SCALING UP TO FULL COVERAGE IN 2008

Given that our model assumes full coverage of LLINs by the end of 2008, it is instructive to look at costs before 2008 carefully. To reach full coverage of all interventions by 2008, the international community needs to begin planning ahead to guarantee sufficient production of LLINs and ACT treatment courses. Full coverage in 2008 means that around 352 million nets must be distributed in Africa by the end of that year. Around 20 million nets have been distributed in 2005 (the Global Fund to fight AIDS, TB and Malaria—the largest provider of resources for malaria control in Africa—has approved purchases of ≈ 22 –31 million LLINs between 2005 and 2007, and we looked at the GFATM disbursement reports and found that ≈ 20 million nets had been distributed in 2005).

TABLE 2
Cost estimates, yearly totals (in millions of US\$)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
LLINs	700	770	854	58	199	760	831	916	121	263	547
IRS	223	187	191	195	200	204	209	213	218	222	206
CHW	645	660	676	692	708	724	741	758	776	793	717
Microscopy	28	28	29	30	30	31	32	33	33	34	31
Human resources	677	693	709	726	743	760	778	796	814	832	753
RDT	40	33	25	26	26	27	27	28	29	29	29
ACTs	109	168	212	217	222	227	232	238	243	249	212
Other drugs	26	13	0	0	0	0	0	0	0	0	4
Severe malaria	54	45	34	35	36	36	37	38	39	40	39
IEC	7	7	7	8	8	8	8	8	9	9	8
Monitoring & evaluation	176	182	192	139	152	194	203	212	160	173	178
Global overhead costs	268	279	293	212	232	297	310	324	244	264	272
Total	2,953	3,065	3,222	2,337	2,556	3,270	3,408	3,564	2,684	2,908	2,997
Total per total population (dollars)	\$3.24	\$3.29	\$3.39	\$2.41	\$2.58	\$3.23	\$3.30	\$3.38	\$2.49	\$2.65	\$3.00
Total per person at risk (dollars)	\$4.40	\$4.46	\$4.58	\$3.24	\$3.47	\$4.33	\$4.41	\$4.51	\$3.32	\$3.52	\$4.02

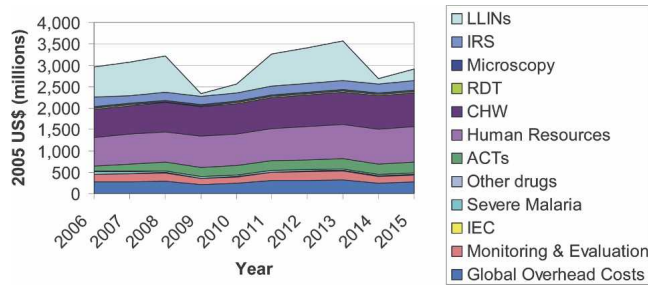


FIGURE 3. Malaria intervention costs (all Africa).

Our costing model above includes a ramping up of distribution to 100 million new nets in 2006, 110 million new nets in 2007, and 122 million new nets in 2008. Because production of LLINs by the two producing companies (Sumitomo Chemical, Japan and Vestergaard Frandsen, Switzerland) in 2006 is currently planned for ≈ 80 million nets, the donor countries should commit as soon as possible to funding a scale-up of production in 2007 and 2008 so that full coverage can be reached by 2008. Two other LLIN products from other manufacturers are also expected to be in the market soon, which would alleviate the production capacity constraint.

With regard to treatment, the current estimate for production of ACTs in 2006 is 130 million treatment doses, which is insufficient to meet the estimated 395 million treatments needed. In 2006 and 2007, our costing model assumes that fevers that cannot be treated with ACTs will be treated with either SP-amodiaquine combination or SP-chloroquine combination, which both cost \approx US\$0.10. By 2008, we assume that enough ACTs will be produced to meet the need, which our projections show to be ≈ 251 million treatment courses. This implies a doubling of ACT production between now and 2008. For our model, we use the estimated 130 million treatment courses for 2006 production, and to ramp up to 251 million by 2008, we use 200 million as the number of ACT treatments produced in 2007. Again, because ACTs are produced by private companies, this increase in production can only happen if donors agree in advance to purchase the required treatment courses.

Note that this costing exercise was carried out in early 2006; because scale-up in 2006 has been slower than expected, this implies that a faster scale-up will be needed in 2007 and 2008, and full coverage could perhaps be reached by early 2009. The important point, however, is that full coverage can be reached within ≈ 3 years, and average annual costs between now and 2015 are not high.

CONCLUSION

We have used a GIS-based method to estimate the population in Africa at risk of contracting malaria and proceeded to calculate the cost of providing this population a comprehensive set of interventions to reduce malaria incidence and mortality. The interventions in our model are adjusted for urban areas and for unstable transmission areas. Although these estimates are rough and cannot replace country-specific malaria planning and cost estimates, the exercise shows that a GIS-based costing strategy comes up with comparable results to methods that estimate population at risk using survey

methods. In areas where survey methods may severely underestimate population at risk, GIS-based estimates provide a useful alternative method. Ideally, maps of malaria risk and intensity will be updated frequently in the future to provide up-to-date estimates given the impact of interventions. Our results make it evident that the costs of comprehensive malaria interventions are very low on a per-capita or per-patient basis. Nevertheless, full coverage is beyond the reach of African government budgets. Given that the disease kills millions, is readily preventable and curable, and has been shown to hamper economic development, the international community should seize the opportunity to reduce massively this human disease burden at such a low cost. Other public health efforts, such as measles and polio campaigns currently underway, present an opportunity to synergize by also delivering malaria interventions, especially bed nets.^{27,28}

Received August 21, 2006. Accepted for publication February 3, 2007.

Acknowledgments: The authors thank Drs. Simon Hay and Robert Snow for providing the Lysenko and malaria risk maps for our use. In addition, Dr. Yemane Ye-ebiyo Yihdego was enormously helpful in clearing up details in the costing. Dr. Maru Aregawi Weldedawit kindly provided some references in the epidemiology literature. Finally, thanks to Adam Storeygard and Yuri Gorokhovich for answering questions on GIS software.

Authors' addresses: Awash Teklehaimanot, 2910 Broadway, MC 3277, Hogan Hall, 110B, The Earth Institute at Columbia University, New York, NY 10025, E-mail: awash@ei.columbia.edu. Gordon C. McCord and Jeffrey D. Sachs, 314 Low Library, MC 4327, Columbia University, 535 West 116th Street, New York, NY 10027, Fax: +1 (212) 854-8702, E-mails: gm2101@columbia.edu and sachs@columbia.edu.

Reprint requests: Awash Teklehaimanot, 2910 Broadway MC 3277 Hogan Hall, 110B New York, NY 10025, Fax: +1 (212) 854-0274, E-mail: awash@ei.columbia.edu.

REFERENCES

- Breman JG, Alilio MS, Mills A, 2004. Conquering the intolerable burden of malaria: what's new, what's needed: a summary. *Am J Trop Med Hyg* 71 (Suppl): 1–15.
- UN Millennium Project, 2005. *Coming to Grips with Malaria in the New Millennium*. Task Force on HIV/AIDS, Malaria, TB and Access to Essential Medicines, Working Group on Malaria. Sterling, VA: Earthscan.
- WHO, 1996. World malaria situation in 1993. *Wkly Epidemiol Rec* 19: 17–22.
- Snow RW, Eckert E, Teklehaimanot A, 2003. Estimating the needs for artesunate-based combination therapy for malaria case-management in Africa. *Trends Parasitol* 19: 363–369.
- Craig MH, Snow RW, le Sueur D, 1999. A climate-based distribution model of malaria transmission in sub-Saharan Africa. *Parasitol Today* 15: 105–111.
- Snow RW, Craig M, Deichmann U, Marsh K, 1999. Estimating mortality, morbidity and disability due to malaria among Africa's non-pregnant population. *Bull World Health Organ* 77: 624–640.
- Snow RW, Guerra CA, Noor AM, Myint HY, Hay SI, 2005. The global distribution of clinical episodes of *Plasmodium falciparum* malaria. *Nature* 434: 214–217.
- Center for International Earth Science Information Network (CIESIN), Columbia University, International Food Policy Research Institute (IFPRI), The World Bank, Centro Internacional de Agricultura Tropical (CIAT), 2004. *Global Rural-Urban Mapping Project (GRUMP): Urban/Rural Extents*. Palisades, NY: CIESIN, Columbia University. Available at: <http://sedac.ciesin.columbia.edu/gpw>. Downloaded March 2006.
- Hay SI, Guerra CA, Tatem AJ, Noor AM, Snow RW, 2004. The

- global distribution and population at risk of malaria: past, present and future. *Lancet Infect Dis* 4: 327–336.
10. Lysenko AJ, Semashko IN, 1968. Geography of malaria. A medico-geographic profile of an ancient disease. In: Lebedew AW, ed. *Itogi Nauki: Medicinskaja Geografija*. Moscow, USSR: Academy of Sciences, 25–146.
 11. Curtis C, Maxwell C, Lemnge M, Kilama WL, Steketee RW, Hawley WA, Bergevin Y, Campbell C, Sachs J, Teklehaimanot A, Ochola S, Guyatt H, Snow RW, 2003. Scaling-up coverage with insecticide-treated nets against malaria in Africa: who should pay? *Lancet Infect Dis* 3: 304–307.
 12. WHO, RBM, UNICEF, PSI, MSH, 2004. *Sources and Prices of Selected Products for the Prevention, Diagnosis and Treatment of Malaria*. Geneva: WHO.
 13. Kiszewski AE, Teklehaimanot A, 2004. A review of the clinical and epidemiologic burdens of epidemic malaria. *Am J Trop Med Hyg* 71 (Suppl 2): 128–135.
 14. Alemayehu T, Ghebreyesus TA, Witten KH, Bosman A, Teklehaimanot A, 1998. Community-based malaria control programme in Tigray Region, Northern Ethiopia: results of a mortality survey of rural under-five children. *Ethiopian J Health Dev* 12: 203–211.
 15. WHO, 2005. *The Role of Laboratory Diagnosis to Support Malaria Disease Management: Focus on the Use of RDTs in Areas of High Transmission*. Report of informal consultation, October 25–26, 2004. Geneva: WHO (prepublication copy). Available at: <http://www.who.int/malaria/docs/ReportLABdiagnosis-web.pdf>. Accessed December 30, 2006.
 16. Lengeler C, 2004. Insecticide-treated bed nets and curtains for preventing malaria. *Cochrane Database Syst Rev.*, Issue 2.
 17. WHO, UNICEF, 2003. *Africa Malaria Report, 2003*. Available at: <http://www.who.int/malaria/amd2003/amr2003/pdf/amr2003.pdf>. Accessed December 30, 2006.
 18. Maxwell CA, Msuya E, Sudi M, Njunwa KJ, Carneiro IA, Curtis CF, 2002. Effect of community-wide use of insecticide-treated nets for 3–4 years on malarial morbidity in Tanzania. *Trop Med Int Health* 7: 1003–1008.
 19. Nevill CG, Some ES, Mung'ala VO, Mutemi W, New L, Marsh K, Lengeler C, Snow RW, 1996. Insecticide-treated bednets reduce mortality and severe morbidity from malaria among children on the Kenyan coast. *Trop Med Int Health* 1: 139–146.
 20. Novartis, 2006. Novartis announces initiative to improve access to state-of-the-art anti-malarial treatment Coartem. Media release, September 29, 2006. Available at: <http://www.novartis.com>. Accessed January 31, 2007.
 21. WHO, 2006. *Guidelines for the Treatment of Malaria*. Geneva: WHO.
 22. RBM, 2006. *ACTs Procured by WHO and UNICEF*. Available at: http://www.rbm.who.int/docs/mmss/actSourcesPrices_catalogue.pdf. Accessed December 30, 2006.
 23. WHO/AFRO, 2002. *Clinical, Behavioural and Socioeconomic Factors Related to Severe Malaria: A Multicentre Study in the African Region*. Available at: http://www.who.int/malaria/cmc_upload/0/000/016/330/multicenter.pdf. Accessed December 30, 2006.
 24. Greenwood B, Marsh K, Snow R, 1992. Why do some African children develop severe malaria? *Parasitol Today* 8: 381–383.
 25. Bryce J, ROUNGOU JB, Nguyen-Dinh P, Naimoli JF, Breman JH, 1994. Evaluation of national malaria control programmes in Africa. *Bull World Health Organ* 72: 371–381.
 26. Kiszewski A, Johns B, Schapira A, Delacollette C, Crowell V, Tan-Torres T, Ameshawa B, Teklehaimanot A, Nafotraore F, 2007. Estimated global resources needed to attain international malaria control goals. *Bull World Health Organ* 85: 569–648.
 27. Grabowsky M, Nobiya T, Ahun M, Donna R, Lengor M, Zimmerman D, Ladd H, Hoekstra E, Bello A, Baffoe-Wilmot A, Amofah G, 2003. Linking ITN distribution to measles campaigns achieves high and rapid coverage at low cost. *Proceedings of the Annual Meeting of the American Society of Tropical Medicine and Hygiene*, Philadelphia, PA, December 4. Northbrook, IL: ASTMH, Abstract 1230.
 28. American Red Cross, CORE, 2004. *Malaria Case Study Partnerships in Action: An Integrated Approach to Combining a Measles Campaign with a Bed Net, Vitamin A and Mebendazole Campaign in Zambia*. Available at: http://pdf.dec.org/pdf_docs/PNADB968.pdf.