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# The impact of indoor residual spraying on malaria incidence in East Shoa Zone, Ethiopia

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**Background:** In Ethiopia, nearly 70% of the population resides in areas prone to malaria infection. The objective of this study is to evaluate the impact of indoor residual spraying (IRS) on the incidence of malaria in East Shoa Zone of Ethiopia.

**Methods:** Data from the registers of malaria cases at Debrezeit Malaria Control Center in East Shoa Zone of Ethiopia were collected and analyzed. Records of 22 villages with no previous rounds of spraying that were entirely covered with IRS using DDT during the peak malaria transmission season of 2001 and 2002 and other 22 adjacent villages with similar malaria incidence but remained unsprayed were used for the analyses.

**Results:** The incidence of malaria in 2011 and 2002 among the sprayed villages was lower than the respective preceding years for both *Plasmodium* species (incidence rate ratio 0.60; CI 0.35 to 0.95;  $p < 0.0001$ ). After the focal spray, there was significant reduction in malaria incidence in the villages sprayed. Spraying was associated with a 62% reduction in malaria incidence.

**Conclusions:** This study demonstrated that IRS with DDT was effective in reducing malaria incidence in highland epidemic-prone areas in the East Shoa Zone of Ethiopia. A larger scale study should evaluate the effectiveness of DDT in reducing malaria incidence against its environmental impact and alternative strategies for malaria prevention.

Keywords: malaria; Africa; Ethiopia; insecticide; indoor residual spraying; DDT; mosquitoes

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Malaria is one of the world's most important parasitic diseases causing a major public health problem. An estimated 3.3 billion people were at risk of malaria in 2010, although, of all geographical regions, populations living in sub-Saharan Africa have the highest risk of acquiring the disease (1). In the same year, there were an estimated 216 million episodes of malaria of which about 81% of cases and 91% of deaths were estimated to have occurred in the WHO African Region, with children under 5 years of age and pregnant women were the ones most severely affected (1).

In Africa, 30% of outpatient consultations, 20–50% of hospital admissions, and 20% of under-5 mortality are due to malaria (2). The disease seems to be extending to previously malaria-free, highland fringe areas, for reasons that are not well understood but probably include drug and insecticide resistance, changes in land use, population movement, and other ecological changes (3).

Malaria is widespread in Ethiopia, with nearly 55 million out of the 83 million people being at risk of infection (4). In most areas of the country, malaria transmission is seasonal, from September through November, shortly after the main rainy season, and from April to May, after brief rains in March and April. However, malaria transmission is very low or nonexistent during the long dry season in most parts of the country.

The two most important malaria parasite species in Ethiopia are *Plasmodium falciparum* and *Plasmodium vivax*, which account for 70% and 30% of all laboratory confirmed cases, respectively (4). The principal vector of malaria is *Anopheles arabiensis*, and most vector control activities are targeted against this species.

The national malaria prevention and control strategy includes indoor residual spraying (IRS), environmental control use of long-lasting insecticide-treated nets (LLINs), and effective case management. IRS using DDT began in the 1950s and showed that IRS could

reduce transmission of malaria in Ethiopia (5). The basic principle behind IRS is that, after biting, the female mosquito eventually rests on sprayed surfaces of the house, where it picks up a lethal dose of insecticide, thus preventing transmission of the parasite to others. Therefore, for IRS to be effective, the mosquito must rest indoors and be susceptible to the insecticide in use. Depending on the type of insecticides used, IRS is also found to protect inhabitants against mosquito bites by diverting the vector from entering a sprayed house, an effect known as excito-repellency.

Each year, malaria endemic villages are classified for two, one, or zero rounds of spraying depending on such factors as the availability of surface water suitable for mosquito breeding, frequency and magnitude of past malaria epidemics, rainfall pattern, and accessibility to health services. When malaria cases show an unusual increase in a village classified for zero rounds, focal spraying may be carried out.

Recent studies on the resting behaviour of the principal malaria vector in Ethiopia indicated an increase in the degree of exophily (resting outside) (6). Although IRS using DDT is being used as one malaria prevention strategy, studies conducted in the central part of Ethiopia have showed an increase in physiological resistance of the vector to DDT (6–11). The objective of this study is, therefore, to evaluate the impact of indoor residual spraying on the incidence of malaria in highland fringe area of Ethiopia using retrospective-confirmed malaria morbidity and spray data from the Debrezeit Malaria Control Center.

## Materials and methods

### Study area and sample

Data for this study were obtained from Debrezeit Malaria Control Center, which has 108 villages with a population of 172,994. The center is located about 50 km east of Addis Ababa. The climate is subtropical, with annual average rainfall of 866 mm, average relative humidity of 61.3%, and average minimum and maximum temperatures of 14°C and 26°C, respectively. The main rains start in June and continue through September, with maximum precipitation in August. The average altitude of the area is 1,850 m. Inhabitants of these villages receive malaria diagnosis and treatment at Debrezeit Malaria Control Center.

Although the area had little ongoing transmission and only intermittent epidemics of malaria, the incidence of malaria increased over time in the area. To devise an evidence-informed decision-making process in the control of the disease, a weekly data collection system stratified by village was introduced at the Center in 1995. The weekly surveillance system was used to monitor trends in

malaria incidence and to identify villages most affected for further consideration of malaria control measures.

In 2001 and 2002, 22 villages with the highest malaria incidence were selected and fully covered with IRS during the peak transmission season. However, 22 adjacent villages with the same weather patterns, vector density, and malaria incidence remained unsprayed. Residents of all villages did not use LLINs during the study period.

Hudson X-expert sprayers were used to spray the interior walls, ceilings, and eaves of houses and livestock and poultry sheds were sprayed with 75% DDT wettable powder at a dosage of 2 g active ingredient per square meter. Over 90% coverage was attained in nearly all villages as shown in Table 1.

### Village selection for spraying and control group

Not all villages that required spraying were included in the spraying programme due to resource limitations. Although 44 villages under Debrezeit Malaria Control Center had high malaria incidence, the available resources dictated spraying of only half of those villages. If a village was selected, the adjacent ones with lower malaria incidence remained unsprayed. Consequently, 22 villages were sprayed, and 22 nearby villages were left unsprayed.

All 22 sprayed and 22 unsprayed villages were included in the study. Sufficient information with respect to spraying, morbidity, and census data for the time of the study period was gathered for both groups. The study was restricted to the four districts found closer to the Debrezeit Malaria Control Center to minimize variation due to differential access to diagnosis.

### Measurements

We obtained weekly microscopically confirmed malaria morbidity data for 44 sprayed and unsprayed villages from 1999 to 2002 (2 years data prior to intervention and 2 years during intervention). The data were disaggregated by villages and species of the parasite and spraying-related variables that included total structural units, proportion of houses sprayed, population covered by the spray, type of insecticide used, and date of spraying for both 2001 and 2002.

The weekly morbidity data were aggregated to 6 months for both sprayed and unsprayed villages for comparison. In the study villages, spraying was done in the months of July and August to control epidemics that occur mainly from September to November. We, therefore, collapsed the 6 months data from September to February to evaluate the 6-month effect of DDT spraying on malaria incidence.

**Table 1.** Number of unit structures sprayed and percentage of unit structures and population covered by spraying in 2001 and 2002

Village	Year of spraying							
	2001				2002			
	Total unit structures*	Sprayed	% Sprayed	% Population covered	Total unit structures	Sprayed	% Sprayed	% Population covered
Alge	625	607	90	94	651	604	93	97
Babo-Gaya	657	646	98	97	794	744	94	97
Ful-xino	396	395	99.9	99.9	435	421	97	95
Godety	308	290	94	95	327	312	95	96
Harewa	174	169	97	98	180	176	98	99
Sardo	393	376	96	99	393	370	94	96
Dalota-Gote	511	485	95	96	714	652	91	98
Kality	391	381	97	99.9	425	399	94	92
Delo	586	571	97	99.9	596	561	94	92
Dambi-1	544	515	92	96	347	305	88	98
Dambi-2	343	319	93	98	577	540	94	97
Ganda gorba	212	194	92	94	218	203	93	97
Denema	437	411	94	96	445	417	94	96
Yatu	341	339	99	99	323	306	95	94
Wajjitu	605	596	99	99	695	672	97	96
Dukam Koticha	502	462	92	95	513	482	94	96
Dibdibe	408	404	99	99	417	400	96	95
Godino	810	769	95	97	995	852	96	97
Borer Tina	382	368	96	99	467	451	96	97
Borer Guda	283	273	96	98	347	335	96	98
Kurkura-1	450	439	98	98	–	–	–	–
Kurkura-2	328	312	95	96	–	–	–	–
Koftu	–	–	–	–	630	591	94	98
Kata wara-ganu	–	–	–	–	583	540	93	94

\*Unit structure in malaria vector control context in Ethiopia includes human dwellings and other homesteads found in human compound.

### Data analysis

The data were cleaned, edited, and analyzed using SPSS for Windows version 16. We first compared the incidence of each parasite species in ‘to be sprayed’ and ‘not to be sprayed’ villages during the baseline (1999 and 2000) to test if there was any difference in the incidence of malaria. After intervention, similar comparisons were made between the unsprayed and sprayed villages. Poisson regression was employed to determine the association between DDT house spraying and malaria incidence. Village name was entered into the model as the indicator variable. The analysis was further extended to compare the 2 spraying years (2001 and 2002) with 2 years prespraying (1999 and 2000) using dummy variables for the years and the spray status of villages in that year. As malaria incidence varies with time in Ethiopia, we kept year in the final model.

Thus the model was:

$$\ln(\text{cases}) = (\text{year dummy}) + (\text{village dummy}) + (\text{spray dummy}),$$

with an offset given by the population of the village.

As *P. vivax* tends to cause relapsing clinical malaria and is, therefore, a less-specific indicator of recent transmission than *P. falciparum*, separate analyses were performed for each species.

### Ethical considerations

Since the study was not set up as an experiment directly involving human subjects, ethical approval from National Ethics Committee was not sought. However, approval to use the data for our study was obtained from the Institutional Review Board at Oromia Regional Health Bureau.

## Results

The study demonstrated that focal spraying with DDT had significant impact on malaria incidence. The incidence of malaria in 2011 and 2002 among the sprayed villages was lower than the respective preceding years for both the *Plasmodium* species [incidence rate ratio (IRR) 0.60; CI 0.35 to 0.95;  $p < 0.0001$ ]. The reduction in malaria incidence was highest in Godety village (Table 2).

Before the spraying took place, the villages selected to be sprayed had similar malaria incidence as the villages selected to receive no intervention. However, after the focal spray, there was significant reduction in malaria incidence in the villages sprayed (IRR 0.37; CI 0.37 to 0.39;  $p < 0.0001$ ) (Table 3).

However, malaria incidence in the villages unsprayed remained the same or increased. Using Poisson regression, we estimated the effect of indoor residual of DDT house spraying on malaria incidence by comparing the incidence rate in villages that received spraying for two consecutive years, 2001 and 2002, with villages that were not sprayed in those years after adjusting for the mean incidence in each village and in each year. We found that spraying was associated with a 62% reduction in malaria incidence in sprayed villages as compared to unsprayed villages in prespray years regardless of the species of the parasite.

## Discussion

We found that sprayed villages had significantly lower malaria incidence compared to unsprayed villages. We also found that the intervention villages had lower incidence of malaria after spraying compared to the incidence they had before spraying, indicating the effectiveness of the intervention. IRS using a long-acting insecticide, DDT, together with case management, helped to wipe out malaria completely from Europe, the former Soviet Union, and North America. Significant reduction in the incidence of disease achieved in South East Asia and South America was also attributed to DDT use (12, 13). In India, the disease toll, which was about 75 million per annum in the 1930s, plummeted to 110,000 eight years after implementation of DDT house spraying and was maintained until 1960 (14).

The resting habit of the vector is one of the most important factors that determines efficacy of IRS. Unfortunately, *An. arabiensis*, the principal vector of malaria in Ethiopia, is partially exophilic and, thus, poses a greater challenge to malaria control efforts relying on IRS. Moreover, long-term use of DDT house spraying is seen to have enhanced behavioral resistance of this species (7). In Tanzania, most *An. arabiensis* were found to exit from DDT-sprayed houses just after blood meals, compared with houses that were sprayed with lambda-cyhalothrin from which they left without taking blood

meals (15). One possible explanation behind the vector departing quickly from the sprayed houses was the irritant and exito-repellency effect of DDT. A study conducted in the rift valley of Ethiopia revealed that 43.6% of blood meal-fed *An. arabiensis* exiting the DDT-sprayed houses showed exophilic behavior (7).

Our results demonstrated that IRS with DDT was significantly associated with reduction of malaria incidence. The average effect of spraying was to nearly halve the incidence of *P. falciparum*, with a slightly larger effect for *P. vivax*, comparing the 6-month malaria incidence rates for sprayed villages in 2001 and 2002 with the similar period in the preceding 2 years, 1999 and 2000. Incidence rates computed for each year comparing with prespraying years for villages under intervention and totally unsprayed villages also showed similar associations. In unsprayed villages, the malaria incidence rates for the spraying years were significantly higher than the incidence rates of prespray years. Conversely, in sprayed villages, the incidence rate was significantly lower than during sprayed years as opposed to unsprayed years, indicating strong correlations between spraying and reduction of malaria incidence.

In Tanzania, where *An. arabiensis* alone is identified as the main vector, comparison of average malaria prevalence before and after spraying showed the reduction in prevalence from 86% prior to spraying to 75% after spraying in operational villages but slightly increased in the control (unsprayed) villages (15). In the highlands of Kenya, IRS with DDT was found to reduce malaria incidence significantly (16).

Although there is increasing evidence of both physiological and behavioral resistance of *An. arabiensis* to DDT in Ethiopia, our results indicated that DDT spraying was effective in reducing the burden of malaria at least in the highland area of East Shoa of Ethiopia where DDT has been less frequently used. Hence, the significant reduction of malaria incidence seen after house spraying with DDT might partly be explained by the low use of DDT that might have minimized the level of resistance selection pressure on the vector.

IRS seems to be an excellent remedy in limiting malaria epidemics and reducing the incidence in highland fringe areas. Among others, two important factors might have positively contributed to the effectiveness of house spraying in the study area. First, spraying activities were carried out during malaria epidemics when local people were most in need and fearful of the epidemic, helping to increase public acceptance and hence increased spray coverage. Second, insecticide pressure was low due to less frequent use of DDT in highland fringe areas; hence probably minimal physiological and behavioral resistance might be expected as compared to areas regularly receiving insecticide spray. The third possibility is that



**Table 2.** Comparison of the incidence of malaria before and after DDT spraying, for intervention and control villages

Village	Disease	Before intervention		After intervention		OR (95% CI)	p-value
		n	% Total (PF, PV)	n	% Total (PF, PV)		
Alge	Yes	231	13.6 (8, 5.6)	161	9.2 (5.1, 4.1)	0.30 (0.25–0.37)	<0.001
	No	1,470	86.4	1,590	90.8		
Bagaya	Yes	131	7.7 (3.2, 4.5)	83	4.7 (1.3, 3.4)	0.37 (0.29–0.46)	<0.001
	No	1,573	92.3	1,675	95.3		
Dibdibe	Yes	146	10.8 (6, 4.8)	51	5.1 (2.7, 2.4)	0.52 (0.43–0.62)	<0.001
	No	880	89.2	942	94.9		
Dal-gote	Yes	298	31.7 (11.1, 20.7)	234	24.4 (16.5, 7.9)	0.22 (0.17–0.27)	<0.001
	No	643	68.3	726	75.6		
D/koti	Yes	120	10.2 (6.3, 3.9)	72	5.9 (1.9, 4)	0.40 (0.32–0.50)	<0.001
	No	1,055	89.8	1,147	94.1		
Dalo	Yes	235	16.5 (10, 6.5)	167	11.4 (7.6, 3.9)	0.29 (0.23–0.35)	<0.001
	No	1,191	83.5	1,302	88.6		
Dambi	Yes	109	8.7 (2.6, 6.0)	66	5.1 (1.2, 3.9)	0.39 (0.31–0.50)	<0.001
	No	1,149	91.3	1,232	94.9		
Dambo	Yes	65	10 (6.3, 3.7)	36	5.4 (3.5, 2)	0.45 (0.34–0.39)	<0.001
	No	583	90	628	94.6		
Dhanama	Yes	55	4.2 (1.6, 2.6)	26	2 (0.5, 1.4)	0.53 (0.41–0.68)	<0.001
	No	1,255	48	1,303	98		
Fulxino	Yes	85	8.1 (3.2, 4.8)	41	3.8 (0.7, 3.2)	0.52 (0.42–64)	<0.001
	No	968	91.9	1,042	96.2		
Godety	Yes	309	40.4 (12.2, 28.2)	246	30.8 (9.5, 21.3)	0.20 (0.16–0.25)	<0.001
	No	456	59.6	554	69.3		
G/Garba	Yes	88	9.9 (5.6, 4.3)	49	5.3 (2.7, 2.6)	0.44 (0.35–0.56)	<0.001
	No	804	90.1	879	94.7		
Godino	Yes	106	4.3 (2.2, 2.1)	66	2.7 (1.3, 1.4)	0.38 (0.30–0.48)	<0.001
	No	2,344	95.7	2,406	97.3		
Harawa	Yes	42	5.5 (2.6, 2.9)	17	2.2 (0.8, 1.4)	0.60 (0.46–0.76)	<0.001
	No	727	94.5	771	97.8		
Oftu	Yes	70	7.6 (2.5, 5.1)	37	3.6 (0.7, 2.9)	0.47 (0.37–0.60)	<0.001
	No	850	92.4	988	96.4		
Sardo	Yes	283	25.2 (13.5, 11.8)	209	18.2 (9.5, 8.7)	0.26 (0.22–0.32)	<0.001
	No	838	74.8	938	81.8		
Wajitu	Yes	73	4 (1.8, 2.2)	45	2.4 (0.8, 1.6)	0.34 (0.29–0.51)	<0.001
	No	1,739	96	1,798	97.6		
Yatu	Yes	64	6.5 (2.9, 3.7)	25	2.5 (0.5, 2)	0.61 (0.50–0.74)	<0.001
	No	916	93.5	991	97.5		
Kaliti	Yes	152	13.4 (5.5, 7.8)	91	7.8 (2.8, 4.9)	0.40 (0.33–0.49)	<0.001
	No	986	86.6	1,083	92.2		
B Guda	Yes	89	8.2 (4.4, 3.8)	50	4.5 (2.6, 1.9)	0.44 (0.35–0.55)	<0.001
	No	1,000	91.8	1,066	95.5		
Borartina	Yes	169	11.5 (2.8, 8.6)	75	5 (1.8, 3.2)	0.57 (0.49–0.64)	<0.001
	No	1,306	88.5	1,430	95		
K/W/ganu	Yes	168	23.9 (8.5, 15.4)	116	15.6 (5.7, 10)	0.31 (0.25–0.39)	<0.001
	No	534	76.1	626	84.4		

Parameters are obtained from Poisson regression model.

the vector might be physiologically resistant to the insecticide but DDT might still have an effect of reducing malaria incidence due to its excito-repellent effect. In

India where the vector was previously found to be resistant to DDT, the same insecticide was able to reduce malaria incidence significantly (17).

**Table 3.** Comparison of the incidence of malaria in DDT sprayed (intervention) vs. non-sprayed (control) villages

Village	Disease	Intervention		Control		OR (95% CI)	p-value
		n	% Total (PF, PV)	n	% Total (PF, PV)		
Alge	Yes	161	9.2 (5.1, 4.1)	274	14.8 (6.8, 8)	0.41 (0.36–0.48)	<0.001
	No	1,590	90.8	1,576	85.2		
Bagaya	Yes	83	4.7 (1.3, 3.4)	112	6.6 (2.5, 4.1)	0.32 (0.25–0.41)	<0.001
	No	1,675	95.3	1,735	93.4		
Dibdibe	Yes	51	5.1 (2.7, 2.4)	159	15.2 (5.5, 9.6)	0.68 (0.61–0.76)	<0.001
	No	942	94.9	890	84.8		
Dal-gote	Yes	234	24.4 (7.9, 16.5)	377	34.2 (11.2, 23)	0.33 (0.28–0.38)	<0.001
	No	726	75.6	667	65.8		
D/koti	Yes	62	5.9 (1.9, 4.)	171	13.3 (5, 8.3)	0.58 (0.51–0.66)	<0.001
	No	1,147	94.1	1,117	86.7		
Dalo	Yes	168	11.4 (3.9, 7.6)	178	11.5 (3.9, 7.5)	0.06 (0.03–0.10)	<0.001
	No	1,302	88.6	1,375	88.5		
Dambi	Yes	66	5.1 (1.2, 3.9)	112	8.2 (2.3, 5.9)	0.41 (0.33–0.51)	<0.001
	No	1,232	94.9	1,260	91.8		
Dambo	Yes	46	5.4 (2, 3.5)	76	10.8 (2.4, 8.4)	0.53 (0.43–0.65)	<0.001
	No	628	94.6	625	89.2		
Dhanama	Yes	26	2 (0.5, 1.4)	23	1.6 (1.1, 0.6)	435 (140–1,348)	<0.001
	No	1,303	98	1,382	98.4		
Fulxino	Yes	41	3.8 (0.7, 3.2)	150	13.3 (5.2, 8.1)	0.73 (0.66–0.80)	<0.001
	No	1,027	96.2	978	86.7		
Godety	Yes	146	30.8 (9.5, 21.3)	149	17.6 (5, 12.6)	6.7 (5.6–8.01)	<0.001
	No	554	69.3	697	82.4		
G/Garba	Yes	49	5.3 (2.7, 2.6)	143	14.6 (5.6, 9.0)	0.66 (0.58–0.74)	<0.001
	No	879	94.7	837	85.4		
Godino	Yes	66	2.7 (1.3, 1.4)	107	4.1 (1.3, 2.8)	0.38 (0.30–0.49)	<0.001
	No	2,409	97.3	2,509	95.9		
Harawa	Yes	17	2.2 (0.8, 1.4)	43	5.2 (2.6, 2.5)	0.61 (0.48–0.77)	<0.001
	No	771	97.8	789	94.8		
Oftu	Yes	37	3.6 (0.7, 2.9)	34	3.1 (0.6, 2.6)	330 (106–1,022)	<0.001
	No	988	96.4	1,049	96.9		
Sardo	Yes	209	18.2 (9.5, 8.7)	241	19.9 (7.1, 12.8)	0.13 (0.10–0.18)	<0.001
	No	938	81.8	971	80.1		
Wajitu	Yes	45	2.4 (0.8, 1.6)	92	4.7 (2.7, 2)	0.51 (0.42–0.62)	<0.001
	No	1,798	97.6	1,855	95.3		
Yatu	Yes	25	2.5 (0.5, 2)	37	3.4 (1.3, 2.1)	0.32 (0.20–0.52)	<0.001
	No	991	97.5	1,037	96.6		
Kaliti	Yes	91	7.8 (2.8, 4.9)	221	18.1 (6.2, 11.9)	0.60 (0.51–0.66)	<0.001
	No	1,083	92.2	1,046	81.9		
B Guda	Yes	50	4.5 (2.6, 1.9)	42	3.6 (1.4, 2.1)	134 (67–267)	<0.001
	No	1,066	95.5	1,137	96.4		
Borartina	Yes	75	5 (1.8, 3.2)	166	10.4 (4.3, 6.4)	0.55 (0.48–0.63)	<0.001
	No	1,430	95	1,425	89.6		
K/W/ganu	Yes	116	15.6 (5.7, 10)	238	30.4 (15.4, 14.9)	0.51 (0.45–0.58)	<0.001
	No	626	84.4	546	69.6		
Total	Yes	1,964	6.8	3,129	9.9	0.37 (0.37–0.39)	<0.001
	No	27,068	93.2	28,602	90.1		

Parameters are obtained from Poisson regression model.

It is a well-established fact that house spraying with insecticides has shown to have dramatic effects in reducing malaria incidence where malaria vectors are highly endophilic (like *Anopheles funestus*) and less effective where *An. arabiensis* is the main vector, due to both resistance and exophilic habits of the vector. Review of the impact of IRS on malaria incidence in various studies has also indicated that, in randomized controlled studies in areas of unstable malaria, the effect ranged from 2% to 98% for the two common malaria parasites (*P. vivax* and *P. falciparum*), which is consistent with our findings (18).

Although our study demonstrated that IRS using DDT is effective, future research should evaluate the environmental impact of DDT in line with the effect that it has on the reduction of malaria incidence in comparison with other alternative strategies. Our study was not without limitations. The level of susceptibility status and behavioral resistance of the main vector of malaria in the study area was not determined at the time of the study. We, however, tried to support our study with data from the other parts of the country. Parasitological data were obtained from Debrezeit Malaria Control Center and might be subjected to various biases during the collection. However, we believe that the possibility of differential distribution between the sprayed and unsprayed years and villages was unlikely. Also, since the unsprayed villages were adjacent to the intervention villages, they might feel neglected and consequently overreport malaria cases to the Center.

In conclusion, this study demonstrated that DDT was effective in reducing malaria incidence in highland epidemic prone areas of East Shoa zone of Ethiopia during the study period. In areas with relatively intense transmission of malaria where standard WHO susceptibility tests indicated the presence of *An. arabiensis* resistant to DDT and where vectors were known to avoid sprayed surfaces, there is a need to study and determine the comprehensive health gains from house spraying.

There is also a need to compare the magnitude of the effect and cost effectiveness for the use of other chemicals for IRS and insecticide-treated bed nets in Ethiopia.

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SDH conceived the idea of the study and was involved in the design, data collection, analysis, and writing of the manuscript. TTB and TB

were involved in writing of the manuscript. All authors critically reviewed and approved the manuscript.

## Conflict of interest and funding

The authors declare that they have no competing interests.

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