World Health Organization
REGIONAL OFFICE FOR Africa

Demonstrating Cost Effectiveness and Sustainability of Environmentally Sound and Locally Appropriate Alternatives to DDT for Malaria Vector Control in Africa

2009–2017

Project Report

By World Health Organization, Regional Office for Africa, July 2017

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Demonstrating the cost-effectiveness and sustainability of environmentally sound and locally appropriate alternatives to DDT for malaria vector control in Africa

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Final Project Report

WORLD HEALTH ORGANIZATION
REGIONAL OFFICE FOR AFRICA
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Abbreviations and acronyms

ACHE	Acetylcholinestarases
ACT	Artemisinin-based combination therapy
ADI	Acceptable daily intake
AFRO	WHO Regional Office for Africa
An.	*Anopheles*
ANVR	African network on vector resistance to insecticides
AS-AQ	Artesunate-Amodiaquine
BCC	Behavioural change communication
bw	body weight
CEP	Community engagement and participation
COMBI	Communication for behavioural impact
DDT	Dichloro Diphenyl Trichlorethane
EMRO	WHO Regional Office for the Eastern Mediterranean
GEF	Global Environmental Facility
GFATM	Global Fund for Aids Tuberculosis and Malaria
GIS	Geographic Information System
GPIRM	Global plan for insecticide resistance management
ICIPE	International Centre for Insect Physiology and Ecology
IEC	Information education and communication
IMIS	Integrated malaria information system
IRM	Insecticide resistance management
IRMM	Insecticide resistance monitoring and management
IRMP	Insecticide resistance management plans
IRS	Indoor residual spraying
ITN	Insecticide-treated nets
IVM	Integrated vector management
IVM-CW	Integrated vector management community workforce
kdr	knock-down resistance
LLIN	Long- lasting insecticidal nets
LSM	Larval source management
MIS	Malaria Information System
NIP	National implementation plans for the Stockholm Convention
NMCP	National malaria control programme
NSC	National Steering Committee
GPS	Global Positioning System
PCR	Polymerase chain reaction
POPs	Persistent organic pollutants
RBM	Roll Back Malaria

RDT	Rapid diagnostic test
RSC	Regional Steering Committee
TWA	Time-weighted-average
UNEP	United Nations Environment Programme
VCTWG	Vector control technical working group

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At the WHO Regional Office for Africa, activities were coordinated and managed by Dr Birkinesh Ameneshewa, Regional focal person for integrated vector management (IVM), under the supervision of Dr Magaran Monzon Bagayoko, team leader for Protection of the human and environment. Overall direction of the project was by Dr Magda Robalo, Director of the Communicable Diseases Cluster. WHO offices in the project countries played a crucial role in locally coordinating implementation of the project.

Ministries of health in the participating countries (Eritrea, Ethiopia and Madagascar) through their national malaria control programmes (NMCPs), with the support of national project coordinators appointed by WHO, executed all activities undertaken at the country level.

The national project coordinators (Dr Messay Gebremariam in Ethiopia; Dr Naina Razafindraleva and Dr Thierry Franchard in Madagascar; and Dr Emmanuel Chanda in Eritrea) were responsible for technical coordination of country activities and reporting to the WHO Regional Office for Africa. Our appreciation goes to Prof. Maureen Coetzee, Prof. Cliff Mutero, Prof. Immo Kleinschmidt and Prof. Basil Brook who were members of the Regional Steering Committee of the project. They provided expert advice and guidance in the designing, planning and implementation of the project.

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The report was drafted and consolidated by Dr Josiane Etang, a WHO consultant and expert in medical entomology, parasitology and vector control from OCEAC and the Faculty of Medicine and Pharmaceutical Sciences, University of Douala, Cameroon.

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Executive summary

BACKGROUND

DDT is currently used in indoor residual spraying (IRS) for malaria vector control in several countries, in accordance with the recommendations and guidelines of the World Health Organization (WHO). Nonetheless, this chemical is among the 12 persistent organic pollutants (POPs) the production or use of which is restricted by the Stockholm Convention because of the high risk it poses to environmental and human health. To reduce reliance by countries on DDT, integrated vector management (IVM) is being promoted thanks to its cost-effectiveness, ecological soundness, and sustainability. IVM creates the opportunity to implement a combination of chemical and non-chemical methods. A number of non-chemical methods have proven their value in malaria vector control in certain settings, but more work is needed on the incremental impact of these methods when used in conjunction with backbone interventions such as indoor residual spraying (IRS), long-lasting insecticidal nets (LLINs) or case management with artemisinin-based combination therapies (ACTs) for treatment of uncomplicated malaria.

The current project was aimed at 'Demonstrating the cost-effectiveness and sustainability of environmentally sound and locally appropriate alternatives to DDT for malaria vector control in Africa', while developing country capacities to effectively plan, implement, monitor and evaluate vector control interventions that do not involve DDT.

FUNDING AND IMPLEMENTATION

The project was executed by the World Health Organization Regional Office for Africa (AFRO), with funding from the Global Environment Facility (GEF) and four in-kind co-funding institutions with a total budget of US$ 7,125,246. The United Nations Environment Programme (UNEP) was the implementing agency. A collaborative approach was used in planning, funding and implementing alternative interventions in three African countries, namely, Eritrea, Ethiopia and Madagascar. Activities were planned for five years from 2009 to 2014, but were extended to 2017 due to subsequent strategic changes in ongoing malaria control interventions that affected the design and implementation of project activities. A total of ten demonstration districts were selected in the three participating countries; the selection was based on ongoing malaria vector control interventions. Additional criteria were malaria disease burden, accessibility to health services, initial introduction of some supplementary interventions, as well as the presence of other vector-borne diseases wherever applicable. The ten selected demonstration districts included:

(a) Anseba, Debub and Gash-Barka in Eritrea;

(b) Adama, Kafta Humera, Sodo and Tach Armachiho in Ethiopia;

(c) Anjozorobe, Ambalavo and Vatomandry in Madagascar.

However, two districts in Madagascar (Anjozorobe and Ambalavo) were excluded due to policy changes on vector control interventions that affected project design and implementation of alternative interventions.

Five components were developed to guide implementation of the project. This report presents what was accomplished under each component.

KEY ACHIEVEMENTS AND OUTCOMES

Achievements of the executing agency

Five major sets of activities related to project development, coordination, technical support, capacity building, and information-gathering and sharing were conducted by AFRO.

The project was successfully developed and its implementation coordinated with technical support missions to countries. External experts were deployed to support the planning and implementation of project activities. Quarterly and annual reports were produced and submitted to the implementing agency.

To strengthen country capacity in IVM, a regional training course was organized in collaboration with ICIPE in Nairobi, Kenya. A total of 18 staff from the three project countries were trained in IVM from 10 to 23 July 2016.

In terms of information collection and sharing, the 'Atlas on trends and the current status of insecticide resistance in malaria vectors' from 2010 to 2015 was drafted, reviewed by regional experts during the fourteenth annual meeting of the African Network for Vector Resistance (ANVR) in October 2016 and subsequently produced.

A 'report on the status of implementation and coverage of IRS and LLINs in the Region during 2008–2013' was also produced.

Country capacity for malaria diagnosis, treatment, and surveillance was strengthened through the provision of basic equipment (microscopes, GPS devices, kits for monitoring insecticide resistance) and supplies.

Achievements for participating countries

Component 1: Strengthening of national and local capacities for malaria control

A total of 2,764 health staff and community members were trained in four areas of competence in malaria control. These included Diagnosis and case management (45.5%), IVM and IRS (35.5%), Insecticide resistance monitoring and management (IRMM) (2%), Integrated planning, monitoring and surveillance systems (17%). The following commodities were provided to project districts:

(a) Diagnostic tools (microscopes, rapid diagnostic test (RDT) kits and ACT for prompt treatment of all malaria patients;

(b) Stocks of alternative insecticides (bendiocarb, propoxur, pirimiphos-methyl) for emergency preparedness;

(c) Equipment and supplies for spray operations and entomological monitoring and surveillance.

Furthermore, a number of policy and strategic documents were produced by the three countries to guide the interventions. Two referral entomology laboratories were strengthened in Ethiopia and Madagascar. Two non-functional entomological laboratories were rehabilitated in Eritrea. Retroactive and prospective epidemiological data revealed a progressive decline in the number of malaria cases in Eritrea (from 295,665 cases in 1998 to 20,196 in 2015) and Ethiopia (from 78‰–157‰ incidence in 2010 to <11‰ in 2013 and 2014 and 23‰ to 45‰ in 2015). In Madagascar, the number of malaria cases varied from one year to the other, the highest number being recorded in 2015 (≈2,200 cases) and the lowest in 2016 (<800 cases).

Community involvement in IVM was strengthened through different activities: (a) an IVM stakeholder consensus and information and dissemination workshop was held in Eritrea in 2017; (b) information, education and communication (and /behavioural change communication (IEC/BCC) activities were conducted following anthropological studies in 2013 and 2016 in Madagascar and Ethiopia respectively. In Ethiopia, the anthropological study found that 'IEC/ BCC activities for education and sensitization of the public, health workers, and communities about the benefits of IRS, LLINs and environmental management' were inefficient. However, the policy environment was supportive of integration of malaria prevention in health communication. In Madagascar, the community was already deeply engaged in the fight against malaria. The approach to raise their awareness about alternative malaria control methods, therefore, focused on development of their participatory leadership skills through 84 talks, 269 mass sensitization campaigns, 22 group discussions and 17 home visits. In all, 7,423 persons participated. The communication strategy was developed based on the outcome of a community survey; (c) National training courses in IVM were conducted in each country. Data on malaria cases were culled from routine national malaria information systems (MIS) which contain cases notified weekly or monthly by health centres.

Component 2: Implementation of alternative methods of malaria vector control tailored to local circumstances

The malaria control strategies implemented under local conditions were mainly based on a combination of high-coverage LLINs and IRS using alternative chemicals or on non-chemical methods as follows:

(a) LLINs + rotation of bendiocarb and lambda-cyhalothrin IRS + larval control in Eritrea;

(b) LLINs + propoxur IRS vs LLINs + pirimiphos-methyl IRS in Ethiopia;

(c) LLINs alone vs LLINs + pirimiphos-methyl IRS or LLINs + community engagement and participation (CEP) in Madagascar.

In Ethiopia, the alternative insecticide for IRS in 2015 was pirimiphos-methyl. In Madagascar, bendiocarb was utilized in 2014 and pirimiphos-methyl in 2015 and 2016.

Replacement of DDT for IRS took place in 2012 in Eritrea and in 2010 in Ethiopia, but before 2009 in Madagascar. This change was dictated by the status of vector resistance to DDT, preparedness of the country or the availability of alternative chemicals. To evaluate the impact of changing the IRS policy, a retrospective parasitological analysis of cases reported by health facilities and entomological data collected from 2010 to 2017 was conducted. The data revealed a progressive decline in the incidence of malaria in Eritrea and Ethiopia, but not so clearly in Madagascar.

In Eritrea, the malaria burden declined over the years from 45,000 cases in 2012 to 20,196 cases in 2015. The same downward trend was seen in annual mortality from malaria which fell from 20 deaths in 2012 to 11 deaths in 2015. The Gash-Barka and Debub regions contributed more than 80% of malaria cases. Results of a 28-day therapeutic efficacy study of artesunate-amodiaquine (AS-AQ) showed 93.5% efficacy, supporting the continued use of AS-AQ in Eritrea. *Anopheles gambiae s.l.* (mainly *An. arabiensis*) and *An. cinerius* were the predominant malaria vector species. *An. gambiae s.l.* was found to be resistant to DDT and pyrethroids (41%–88% mortality rate), but susceptible to organophosphate and carbamate insecticides (98%–100% mortality rate). Polymerase chain reaction (PCR) analysis revealed the presence of 1014F kdr allele in all tested samples. The residual bio-efficacy of bendiocarb IRS against *An. gambiae* s.l. samples collected from Tesseney, as tested using WHO cone assay, was very low (39% at 55 to 75 days after spray operations).

In Ethiopia, the use of alternative insecticides for IRS was assessed. Malaria parasite prevalence progressively declined from between 10% and 14% in 2012 to <0.2% in 2015 following IRS with propoxur in Cluster I localities or with pirimiphos-methyl in Cluster II localities. The rate of anaemia declined only in Cluster I localities (from 10% in 2012 to 5.4% in

2015). In Cluster II localities, the rate of anaemia remained unchanged (9% to 10.5%). *Anopheles gambiae s.l.* (largely *An. arabiensis*) was the major malaria vector (96.8% of the total number of collected *anopheles*). A progressive decline in *An. gambiae s.l.* density was recorded across most of the demonstration localities from 5 to 35 specimens/ night per room in 2012 to less than 0.8 specimen/night per room in 2015, except in Asherie and Bate Germame where the decrease occurred later in 2015. A vector population behavioural change was suspected as probably due to IRS operations. Various patterns of *An. gambiae s.l.* resistance to insecticides were observed, but resistance to DDT, deltamethrin, lambda-cyhalothrin and malathion was widespread (1%–78% mortality rate). The residual bio-efficacy of IRS with pirimiphos-methyl was low (40.8%–74.17% mortality against susceptible *An. gambiae* at 2–3 months post intervention using WHO cone bioassays).

In Madagascar, three different combinations of alternative interventions were assessed in three study arms as follows: (a) LLINs alone, (b) LLINs + pirimiphos-methyl IRS, and (c) LLINs + community engagement and participation (CEP). In each of the three arms, malaria incidence per 1,000 varied in a bell-shape from 2013 to 2017. The peaks were recorded in 2015, corresponding to 5.5‰, 10.2‰ and 7.0‰ for the LLINs, LLINs + CEP and LLINs + IRS arms respectively. However, the incidence progressively declined to less than 3‰ in 2017 in the three arms. The highest impact was recorded in the LLINs + CEP and LLINs + IRS arms, where incidence fell 41 and 24 times respectively, compared with the four-fold incidence reduction in the LLINs arm.

Overall decline in infection prevalence was 7% to 70% in 2013 and 2% to 3% in 2017. The highest decline was recorded in the LLINs + CEP and LLINs + IRS arms (4 to 8 times reduction compared with a three-fold reduction in the LLINs arm). *Anopheles. gambiae s.l*, *An. funestus* and *An. mascariensis* were identified as the main malaria vectors in Madagascar. The vector biting rates progressively increased from 0.01 bites/person per night in 2013 to 0.1–0.6 bites/person per night in 2016 especially in LLINs + CEP and LLINs + IRS arms, suggesting a weak impact of IRS and CEP on malaria vector density and biting rates, or possible changes in vector resting behaviour in and around sprayed dwellings. Most of the tested *An. gambiae s.l.* and all the *An. mascariensis* populations were susceptible to carbamate and organophosphate insecticides. However, resistance to DDT, permethrin, carbamate and organophosphate insecticides was suspected in several *An. funestus* populations.

In terms of community participation in malaria vector control activities, Eritrea had had long experience. By contrast, a number of weaknesses were identified in IEC/BCC activities in Ethiopia, resulting in very low community participation. The current project, therefore, worked to strengthen community engagement through conducting a situation analysis, training, education and mobilization campaigns using newly-developed audiovisual and print communication tools based on outcomes of the situation analysis. In Madagascar, a comprehensive community survey was carried out and a new IEC/BCC strategy was designed based on the outcomes of the survey, implemented. Impact of the new ICE/BCC tools was assessed.

Risks to humans and the environment deriving from the use of pirimiphos-methyl in IRS were assessed in Ethiopia and Madagascar. Based on these assessments, countries prepared statements on the risks for residents of the sprayed dwellings and people who handle the chemical. Environmental management and monitoring plans were also developed.

Component 3: Management and use of DDT and other public health pesticides and disposal of stockpiles

To improve the management of insecticides used in public health or agriculture, a detailed analysis of insecticide management systems was carried out in Eritrea and Ethiopia. In Ethiopia, national policy documentation and procedures were later developed, and inter-sectoral collaboration strengthened for better management of insecticides. Furthermore, 458 staff from the three project countries were trained in IRS and safe management of insecticides.

The status of insecticide resistance in major malaria vectors, to which poor management of insecticides contributes, was monitored and well documented. Insecticide resistance management (IRM) plans were also produced in the three countries, and 81 staff enrolled in specific IRM training courses.

Component 4: Cross-border information exchanges and technical support to countries

National IVM committees were set up at the beginning of the project in order to advise the national malaria control programmes (NMCPs) and support project implementation and sustainability of outcomes. Furthermore, the three national project coordinators were supported to participate in two annual meetings of a similar project on 'sustainable alternatives to DDT and strengthening of national vector control capabilities' organized by the WHO Regional Office for the Eastern Mediterranean (EMRO), to share lessons, experiences and the final results of the project.

Component 5: Project management

The project management system relied on five bodies operating through vertical channels, for making commitments and maintaining effective communication during the planning, execution, reporting and resourcing processes. These bodies comprise UNEP, WHO-AFRO, the Regional Steering Committee (RSC), ministries of health in the project countries through NMCPs, partners, and local communities.

SUSTAINABILITY

Based on project outcomes, a 'DDT-ALT-Model' was developed to guide the sustainability of country efforts towards reduction of the malaria burden and elimination of DDT use in malaria control. To better implement this Model, the creation of an 'IVM community workforce' (IVM-CW) in each targeted district was recommended. This will enhance community engagement is also expected to benefit control of other vector-borne diseases. Additionally, 8 other mechanisms have been defined to ensure the sustainability of the gains made from this project.

CONCLUSION

The project helped to systematically document the impact of policy changes on the malaria burden. Application of alternative malaria control strategies associated with strong community engagement led to reduction of the disease burden. Evaluation of the cost-effectiveness of alternative interventions was one of the objectives of this project; however, no data on the cost of alternatives or the link to the observed decline in malaria burden was documented. Lack of this information could negatively impact the sustainability of promoted IVM strategies at country level. Further support is needed to investigate the cost effectiveness of alternative interventions, the patterns of vector behaviour in the presence of interventions, the trends in vector resistance to all the insecticides in use, mechanisms involved, and the applicability of newly-developed alternatives at the larger-scale programme level.

RECOMMANDATIONS

In order to promote actions for DDT elimination in malaria control, eight (8) recommendations have been made to countries and supporting institutions; including the following two key recommendations:

To countries:

- Define locally-adapted integrated strategies aimed at reducing insecticide pressure, thus preventing or delaying development of insecticide resistance and reducing dependence on chemical insecticides, while reducing the malaria burden and eliminating DDT use, as shown in the DDT-Alt-Model.

To AFRO, UNEP and GEF:

- Further stimulate country efforts towards elimination of DDT in malaria control and promote research on alternative malaria vector control tools.

1. Introduction

Malaria is a major public health problem and an obstacle to socio-economic development in most of the countries in the tropical world, especially in Africa. In 2016, the number of malaria cases worldwide was estimated at 212 million (148 million to 304 million), leading to 429,000 (235,000–639,000) deaths, most of them in children under 5 years of age (92%) in Africa; compared with the year 2000, however, incidence has dropped by 41% and the mortality rate by 62% [1].

One of the key components of the 'Global technical strategy for malaria 2016–2030' (GTS) is vector control aimed at shortening the lifespan of mosquitoes near their human targets [2, 3]. Currently, primary malaria vector control interventions involve the use of insecticides either through insecticide-treated nets (ITNs) or indoor residual spraying (IRS) of houses, which are the most effective ways of obtaining large-scale benefits at affordable cost. In addition, accurate diagnostic testing and prompt treatment using artemisinin-based combination therapy (ACT) are the current hallmarks of uncomplicated malaria treatment [2].

ITNs and IRS have been proven to successfully reduce or interrupt malaria transmission when coverage at community level is sufficiently high [3]. In specific settings and under special circumstances, they can be supplemented by other methods such as larval source management (LSM) [4]. IRS involves cyclic spraying with insecticides inside human habitations to reduce mosquito lifespan and density, thereby reducing malaria transmission and preventing epidemics. This method relies on the fact that malaria vectors enter houses during the night to feed on the occupants and rest on the walls or roofs prior to or after feeding [3]. The World Health Organization (WHO) recommends 12 insecticides belonging to four chemical classes for use in IRS, including DDT [5].

However, the Stockholm Convention on persistent organic pollutants (POPs) restricts the production or use of 12 chemicals, including DDT [6]. Nevertheless, DDT is used for disease vector control in accordance with WHO recommendations and guidelines. Accordingly, DDT is used in approximately 24 countries worldwide, 1,000 to 1,300 tons being sprayed annually in the WHO African Region [7]. However, DDT, like other POPs, poses significant global risks because it is toxic, bioaccumulates in the food chain, and is susceptible to long-range environmental transport by air and water. Its extensive use in crop protection resulted in negative effects ranging from the thinning of bird eggshells to developmental and reproductive effects in wildlife [8].

The Stockholm Convention stipulates that parties, within their capabilities, should promote research and development of safe alternative chemicals and non-chemical products, methods and strategies, relevant to their context [9]. However, DDT-using countries in Africa, for the most part, have not been able to appropriately assess and adopt alternative products that would be similarly or more effective, affordable and sustainable than DDT. While these countries are working together under the Roll Back Malaria partnership to strengthen health services and malaria control capabilities in general, there is no coordinated approach to the development, assessment and utilization of alternatives to DDT. Furthermore, there are limitations in the human resources and expertise necessary to deal comprehensively with the prevention of malaria using alternative interventions. There is also limited regulation on the use, transport and storage of pesticides, limited epidemiological surveillance, and inadequate diagnostic and referral services.

Selective and targeted vector control interventions are, therefore, needed to minimize country dependence on DDT, while sustaining efforts towards malaria elimination. Such interventions need to be selected based on evidence at the programme level, and should be evaluated ecologically, entomologically and epidemiologically to inform the policy on the need to change the objectives of vector control programmes over time as the epidemiology of the disease changes. An integrated vector management (IVM) approach was promoted in the planning and selection of alternative methods of vector control [10, 11]. IVM is defined as a process of evidence-based decision-making procedures designed to plan, deliver, monitor and evaluate targeted, cost-effective and sustainable combinations of regulatory and operational vector control measures. IVM can mitigate the risks of vector-borne disease transmission while ensuring the following:

(a) Adherence to the principles of subsidiarity, inter-sectoral collaboration and partnership;
(b) Provision of an adaptive management approach that ensures optimal levels of effectiveness of vector control interventions in local settings for compliance with the requirements of the Stockholm Convention;
(c) Reduced reliance on insecticides for public health protection applications;
(d) Promotion of appropriate management of insecticides, including judicious use and effective handling of stockpiles;
(e) Openness to a pro-active approach to vector-borne disease prevention through the incorporation of environmental management measures in water resources development.

Local elimination of malaria vectors has been achieved with subsidiary interventions other than ITNs and IRS [12]. There are several historical records documenting elimination of African primary vector species from sizeable tracts of land in Egypt and Zambia, primarily through larval source management [13, 14, 15, 16, 17]. Furthermore, in 2000, the South African National Malaria Control Programme (NMCP) embarked on a winter larviciding programme using vectobac (Bti). This has worked well in reducing mosquito density during the winter and summer months, with a concomitant reduction in the number of local malaria cases [18]. Other types of larval source management such as habitat manipulation are encouraged through health promotion messages to community members. Such examples of the successful use of alternatives in the WHO African Region should be examined for wider application.

The current project was aimed at 'demonstrating the cost-effectiveness and sustainability of environmentally sound and locally appropriate alternatives to DDT for malaria vector control in Africa', while developing the capacities of the participating countries to effectively plan, implement, monitor and evaluate vector control interventions that do not involve a short-sighted approach to the use of DDT.

This report presents the overall achievements and outcomes of implementation of the project at the regional level by the executing agency (the WHO Regional Office for Africa) and at the national level by the three implementing countries (Ethiopia, Madagascar, and Eritrea).

2. Objectives

The overall objective of the project was the reduction of DDT use and the sound management of DDT stocks through the strengthening of malaria vector control practices in the three targeted African countries. The short-term objective was to demonstrate cost-effective, environmentally sound, and locally appropriate alternatives to DDT use in malaria control, ensuring their sustainable application through strengthened national and local capacities. In the long term, the project aimed to contribute towards country efforts to diversify vector control tools and move away from the traditional method of blanket house spraying to selective vector control approaches based on evidence.

The specific objectives of the project were:

(a) To strengthen the capacity for vector control and malaria diagnosis and treatment in project districts, particularly for emergency malaria occurrences that may be associated with introduction of alternatives;

(b) To strengthen national and local capacities for planning, monitoring and evaluating vector control interventions;

(c) To strengthen national reference centres to support the implementation of alternative malaria control interventions;

(d) To design, implement, monitor and evaluate studies that will assess the cost-effectiveness and sustainability of alternative interventions;

(e) To strengthen community participation and mobilization to support the sustainable implementation of alternative interventions;

(f) To strengthen pesticide management practices that will prevent the accumulation of DDT and other pesticides in stockpiles and reduce the development of vector resistance;

(g) To assess the potential risks to human health of alternative, non-POP, insecticides;

(h) To disseminate information on the best alternative malaria vector control methods for wider application.

3. Institutions involved

The project was executed by the WHO Regional Office for Africa (Brazzaville, Congo), with funding from the Global Environment Facility (GEF) and co-funding from four other institutions. The United Nations Environment Programme (UNEP) was the implementing agency.

3.1 Funding institutions

The total project cost was USD$ 7 125 246. GEF contributed US$ 3 844 296 (this included the project development fund) and US$ 3 280 950 came from the in-kind co-financing institutions (WHO, RBM, project countries, and ICIPE) (Table 1). The project met the objectives of the GEF operational programme on POPs (OP #14) to provide incremental assistance to developing countries and those with economies in transition to reduce or eliminate the release of POPs into the environment. The expected outcomes and proposed on-the-ground interventions which rely on IVM, are consistent with OP #14 and met the GEF funding criteria under this operational programme.

Table 1: Recapitulation of funding institutions and contributions

Institution	Amount in USD
GEF	Project
	3 460 296
PDF A	0
PDF B	384 000
Subtotal GEF	**3 844 296**
Co-financing	
Governments in kind	1 055 525
Contributions from other organizations in kind	
World Health Organization	1 556 425
Roll Back Malaria	300 000
International Centre for Insect Physiology and Ecology (ICIPE)	55 000
PDF B co-financing	314 000
Subtotal in kind co-financing	**3 280 950**
TOTAL PROJECT COST + PDF B	**7 125 246**

3.2 Implementing agency

Based on its experience in implementing DDT projects in Mexico and Central America, the Middle East and North Africa, South-East Asia and the Western Pacific, UNEP played an important role in the implementation of the current project. UNEP, therefore, brought the respective project managers together to review progress, exchange experiences and find solutions to address common challenges related to implementation of the project.

3.3 Executing agency

The project was executed by the WHO Regional Office for Africa (WHO-AFRO) in Brazzaville, Congo, in collaboration with three African countries:

(a) The Ministry of Health of Eritrea;
(b) The Ministry of Health of Ethiopia;
(c) The Ministry of Health of Madagascar;

WHO took full advantage of the opportunities available to it at global, regional and country levels to identify and allocate appropriate technical support for project implementation, monitoring and evaluation. WHO's own structures, coupled with the opportunities provided by the RBM partnership, provided an ideal and perhaps unique context in which to address the constraints to DDT reduction and elimination. WHO also has the capacity to widely disseminate to all malaria-endemic countries information and experiences gained from the project.

The WHO Regional Office for Africa established a partnership on IVM in 2003. The aim of the partnership was to promote implementation of IVM through broader participation in national programmes with such organizations as UNEP, ICIPE, the Environmental health project, the Hashimoto Initiative, and the Panel of expert on environmental management. The aim of such partnerships is also to promote the implementation of IVM as part of a broader integrated disease management strategy and as a way of preventing the release of persistent organic pollutant (POP) pesticides into the environment.

3.4 Participating countries

The current project was implemented in three African countries: Eritrea (2014–2017), Ethiopia (2009–2017) and Madagascar (2012–2017) (Figure 1).

Malaria transmission and morbidity

Malaria transmission in these countries is characterized by sudden upsurges of morbidity and mortality that have recently been aggravated by population movements, floods and drought. Furthermore, the prevalence of the most deadly species of malaria parasites: *Plasmodium falciparum*, accounts for 95% of malaria infections. The *Plasmodium* parasites are transmitted by specific mosquito vectors that feed on humans, the major vector species being *Anopheles gambiae s.s.*, *An. coluzzi*, *An. arabiensis* and *An. funestus*.

Figure 1: Map of Africa showing the three project countries

Malaria control and DDT use for IRS

Before the implementation of this project in 2009, DDT was used for malaria vector control or kept for the management of insecticide resistance in the three project countries.

Eritrea had implemented a successful malaria control programme that integrates high LLIN coverage, selected IRS, targeted larval source management (LSM), early diagnosis and treatment and effective information, education and behavioral change communication (IEC/BCC) [18]. Depending on the epidemiological situation, the use of DDT until 2011 varied from 7 to 30 tons annually.

In Ethiopia, malaria vector control had relied on IRS since 1960, involving the use of an average of 360 tons of DDT annually. Furthermore, the NMCP emphasized alternative strategies such as ITNs, anti-larval measures, modifications of the physical environment and efficient water management.

In Madagascar, after severe malaria epidemics in highland areas in 1987, DDT was re-introduced for vector control. The quantity of DDT used gradually decreased from 208 tons in 1993 to 60 tons in 2002. DDT is now in the list of public health pesticides to be considered for epidemics response and in the absence of insecticide resistance.

In summary, the baseline for DDT use in these countries was estimated at ≥567 tons per year.

Demonstration districts

Demonstration sites for the project were chosen during national stakeholder meetings that were held in each of the participating countries. A total of 10 project demonstration districts were selected based on ongoing IRS operations for malaria control. Additional criteria that were used during the selection process within the context of IVM were malaria disease burden, accessibility to health services, initial introduction of some alternative interventions that supplement IRS, and the presence of other vector-borne diseases where applicable.

The 10 selected demonstration districts were:

(a) Anseba, Debub and Gash-Barka in Eritrea;

(b) Adama, Kafta Humera, Sodo and Tach Armachiho in Ethiopia;

(c) Anjozorobe, Ambalavo and Vatomandry in Madagascar.

However, two districts in Madagascar, namely, Anjozorobe and Ambalavo, were excluded and the project was implemented only in Vatomandry District due to continued strategic changes in malaria control that were bound to affect project activity implementation.

4. Outcomes of the project

The project was planned to last five years from 2009 to 2014, but it was subsequently extended to 2017, due to strategic changes in ongoing malaria control interventions that affected the design and implementation of project activities. The following project components were executed:

(a) Strengthening of national and local capacities for malaria control;

(b) Implementation of alternative methods and approaches of malaria vector control tailored to local circumstances;

(c) Management and use of DDT and other public health pesticides;

(d) Cross-border information exchanges and technical support;

(e) Project management.

4.1 Achievements of the implementing agency

Implementing agency, UNEP in collaboration with the executing agency developed the project. It also prepared all project related documents such as progress and financial reporting templates and reviewed logical framework and budget plans when required. The agency facilitated and supervised project implementation through reports, monthly teleconferences with the executing agency and co-organizing yearly project coordination meetings. UNEP also monitored project implementation through quarterly financial statements and biannual progress reports submitted by the Executing Agency. The Agency conducted mid-term and project outcome evaluation at the completion of the project. It also made coordination and consultation with the Funding Agency including submission of project implementation progress reports.

4.2 Achievements of the executing agency

Overall, five major activities were conducted by the WHO Regional Office for Africa; they comprised project development in collaboration with implementing agency, coordination, technical support, capacity building, information gathering and sharing. Within these activities, 11 milestones leading to the success of the project were achieved (Table 2).

Table 2: Activities conducted, and milestones achieved by the WHO Regional Office for Africa

Activities	Milestones
Development of the project	• Regular consultations with UNEP for the development and revision of the project implementation plan
Coordination	• Seven Project Steering Committee meetings jointly organized • 20 technical and 28 financial reports produced and submitted • More than 35 teleconferences with participating countries and UNEP held
Technical support	• 8 missions (field visits and national planning meetings) • Regional expertise engaged provided technical support to the project countries (1 to Eritrea, 1 to Ethiopia, and 3 to Madagascar)
Capacity strengthening	• Procurement of insecticides, GPS, insecticide resistance monitoring kits, microscopes • Development of technical documentation (IRMP, IVM, etc.) • Regional training in IVM (18 staff from Eritrea, Ethiopia, Madagascar)
Information collection and sharing	• Documentation and publication of 2008–2013 data on vector control interventions in Africa • Collection of insecticide resistance data from 37 countries and production of a regional atlas

Development of the project

Due to the delay of project inception in Madagascar and the re-engagement of Eritrea at a later stage, the project implementation plan was revised. Approval for the no-cost extension of the end-date of the project to 2017 was requested and obtained from the implementing agency, UNEP.

Coordination

A total of seven steering committee meetings were organized to review the project implementation plan and address all the challenges encountered at regional and country levels. Furthermore, other opportunities such as meetings of the Technical Advisory Committee of the project in the Eastern Mediterranean Region (EMR) were used to organize back-to-back meetings to discuss critical issues and share experiences and lessons.

Quarterly progress reports were also requested from countries and reviewed in order to monitor implementation progress The reports were compiled and submitted to the implementing agency. The WHO Regional Office for Africa produced and submitted 20 technical and 28 financial reports to GEF, in order to update progress and share information.

Frequent teleconferences were held and e-mail communication maintained between the WHO Regional team and the country teams to advise, guide, and support the countries in making decisions and fine-tuning plans to fast-track project implementation.

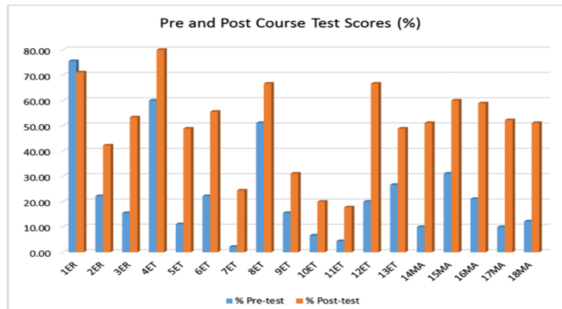


Figure 2: Pre- and post-test scores for 18 participants (ER-Eritrea; ET-Ethiopia; MA-Madagascar) Nairobi, 10-23 July 2016

Technical support

In addition to several in-country missions conducted to support the planning and implementation of the project, external technical experts were identified and sent to project countries in order to strengthen their capacities and support some specific activities related to the project. For instance, an Agreement for performance of work (APW) was signed with a social science expert to support Madagascar in the development of a strategic plan for community information, education and communication (IEC) and social mobilization for behavioural change for malaria control and beyond. Development of the IEC strategic plan was guided by the outcomes of anthropological investigations conducted earlier.

Capacity building

Malaria drugs (artemisinin-based combination therapy – ACT) and rapid diagnostic test kits were procured and delivered to Madagascar in July 2015, to strengthen the diagnosis and treatment capacities of health facilities in the project districts. Microscopes for better diagnosis of malaria in health facilities and for entomological activities were also provided to Ethiopia and Madagascar.

A new formulation of pirimiphos-methyl (Actellic 300 CS) was procured and directly delivered to Ethiopia in 2015 and Madagascar in 2016 and 2017 for indoor residual spraying operations in demonstration arms during the high malaria transmission seasons, while bendiocarb was procured and delivered to Madagascar in 2015

In order to avoid delays due to procurement and custom clearance processes on importation, insecticide resistance monitoring, and bio-efficacy test kits and impregnated papers that are available only at the WHO collaborative laboratory in Malaysia were procured and delivered to the three countries in 2015 and 2016.

Other basic entomological equipment and supplies were procured and delivered to the three countries. These enabled them to conduct entomological surveillance, which generated information on vector and malaria transmission dynamics in relation to the interventions in place.

Bearing in mind that building capacity for IVM in the countries was one of the aims of the project, a regional IVM training course was organized in collaboration with ICIPE in Nairobi, Kenya from 10 to 23 July 2016 (see group photo in Figure 2). A total of 18 NMCP staff drawn from the three participating countries, (Eritrea, Ethiopia and Madagascar) participated in the two-week comprehensive IVM course. The trainees were staff working at national and sub-national levels. Course topics and programmes were prepared with the full involvement of AFRO. The format of the course was participatory to ensure the full involvement of trainees. Problem-solving group sessions were significant parts of the course programme. A pre-test served as the benchmark for evaluating learning outcomes, as deduced from comparing pre-test results with post-test scores at the end of the training. Thus, while only 3 out of 18 trainees scored 50% or higher during the pre-test, 11 out of 18 trainees attained similar scores during the post-test (Figure 3). This was a marked improvement which clearly demonstrated that the course had been effective in increasing IVM knowledge among the trainees.

Figure 3: Group photo of participants and facilitators at the regional IVM training course Nairobi, 10–23 July 2016

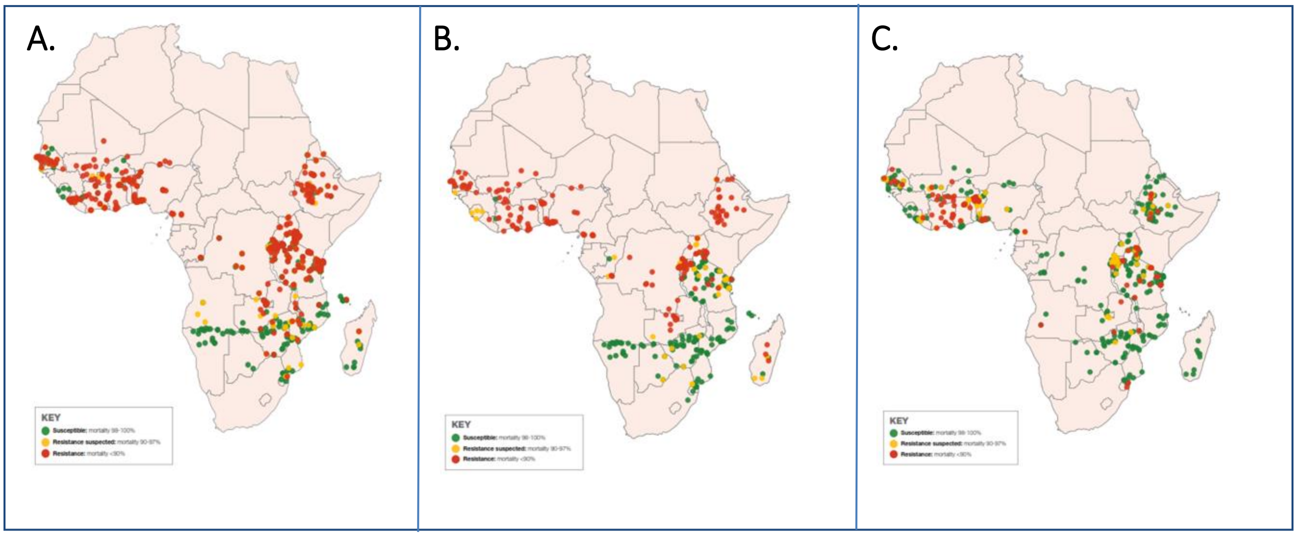
Information collection and sharing

Trends in insecticide resistance. Data on insecticide resistance in the major malaria vectors in Africa, *An. gambiae s.l.* and *An. funestus*, were collected from 1067 localities belonging to 37 countries of the WHO African Region. The information was gathered from NMCPs, research institutions and other partners, analyzed and used to draft a regional atlas. The draft regional 'Atlas on trends and the current status of insecticide resistance in malaria vectors' from 2010 to 2014 was reviewed by regional experts during the fourteenth annual meeting of the African network on vector resistance (ANVR) in October 2016; the Atlas was subsequently produced.

Across the surveyed countries, only one country (Namibia), reported no insecticide resistance in local malaria vectors, although DDT and deltamethrin are in use for malaria vector control in that country. Resistance to DDT and pyrethroid insecticides in *An. gambiae s.l.* tended to be very common (>75% of countries), while carbamate resistance, although less common, was increasing in West Africa (Figure 4). Compared with *An. gambiae s.s.*, DDT and pyrethroid resistance was less frequent in *An. arabiensis*. Resistance of *An. funestus* to insecticides was mostly reported in east and southern Africa, including DDT resistance in Eritrea. These data highlight the need for regular (yearly) monitoring of insecticide resistance, in order to guide the development and implementation of resistance management plans in African countries.

Figure 4: Maps of the status of *An. gambiae s.l.* resistance to pyrethroid (A), DDT (B) and carbamate (C) insecticides

(Source: Atlas on trends and current status of insecticide resistance in malaria vectors of the WHO African Region, 2010-2014)



Deployment of insecticide indoor residual spraying and long-lasting insecticidal nets in Africa. Data on the deployment of malaria vector control interventions (IRS and LLINs) from 2008 to 2014 were collected from 24 countries across the African Region. The aim was to monitor the status of coverage through the years and collect information on the types of insecticide in use in different countries. The report on the management, delivery and use of the two interventions and related issues is now available and is on the AFRO website.

Sharing experience. The three national coordinators of the current project were supported to participate in the meeting on 'sustainable alternatives to DDT and strengthening of national vector control capabilities' organized by EMRO. The aim was to share the final results of a similar project in that region and better understand the extent of the global WHO-UNEP joint effort to address needs in vector control and learn lessons from countries in the Eastern Mediterranean Region.

Producing the final project report and publishing outcomes. A consultant was recruited to compile and analyze the data and prepare the regional project report during two months of consultancy from May to July 2017. The draft report was presented to the Regional Project Steering Committee at its final and closing meeting held from 26 to 28 June 2017 for review and validation. Based on the feedback and comments from the Steering Committee, the report was finalized and submitted to the WHO Regional Office for Africa on 26 July 2017. The outcomes of the project will be synthetized for subsequent publication.

4.3 Achievements for the participating countries

COMPONENT 1: Strengthening of national and local capacities for malaria control

The project strengthened the capacity of countries in various fields of malaria control including programmatic aspects, monitoring-evaluation-surveillance, data management, and community awareness about malaria control in general and alternatives in particular. Figure 5 depicts achievements in those areas.

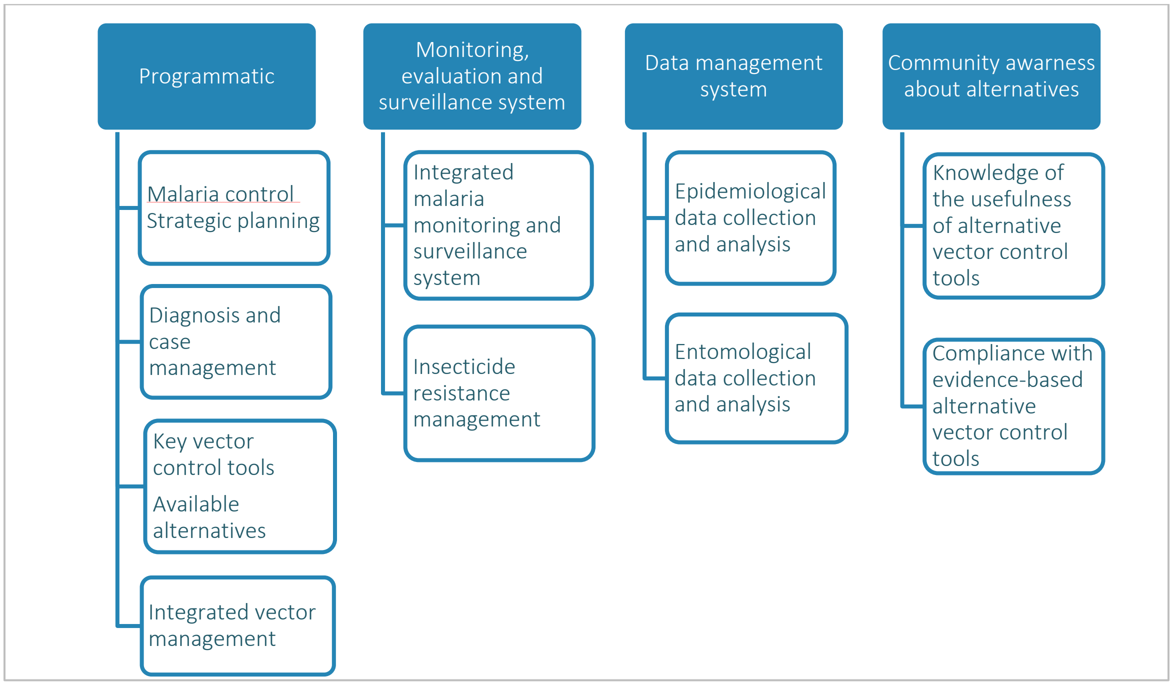


Figure 5: Overview of the strengthened capacities to fast-track DDT elimination and effective implementation of alternatives in project countries.

Expected outcome 1: National and local capacities in planning, monitoring and evaluation of malaria control are strengthened

A total of 34 training sessions were conducted at country level (Figure 6). Six to sixteen training sessions were organized in each country from 2014 to 2017. Figure 7 shows the breakdown of learners from each country by specific aspect of malaria control.

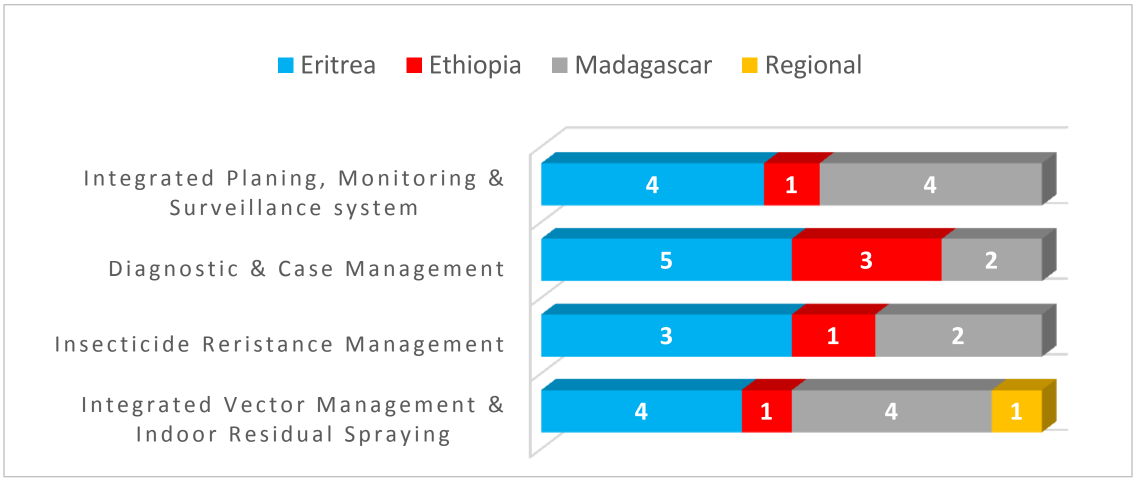


Figure 6: Number of training sessions organized in each area of competence by project country, 2014–2017

Overall, 2,764 health staff and community members were trained in four areas of competence in malaria control:

(a) Diagnosis and case management (45.5%);

(b) Integrated vector management and Indoor residual spraying (35.5%);

(c) Insecticide resistance monitoring and management (IRMM) (2%);

(d) Integrated planning, monitoring and surveillance (17%).

Regarding both IVM and IRS training courses, 980 participants were trained (Figure 7). Of this number, 522 learners received specific training in IVM, which is more than five times higher than the end-of-project target. In other words, a total of 100 staff were trained in IVM. The training focused on acquisition of broad knowledge of effective and locally appropriate vector control methods leading to a drastic reduction in the use of persistent pollutant chemicals. These included housing improvements, environmental sanitation, use of repellents, etc. The trainees included NMCP workers, district and regional health staff, community health workers, and laboratory and field technicians (Figure 8). The training provided a good opportunity for participants to discuss and evaluate the IVM strategy of each country at the policy and implementation levels.

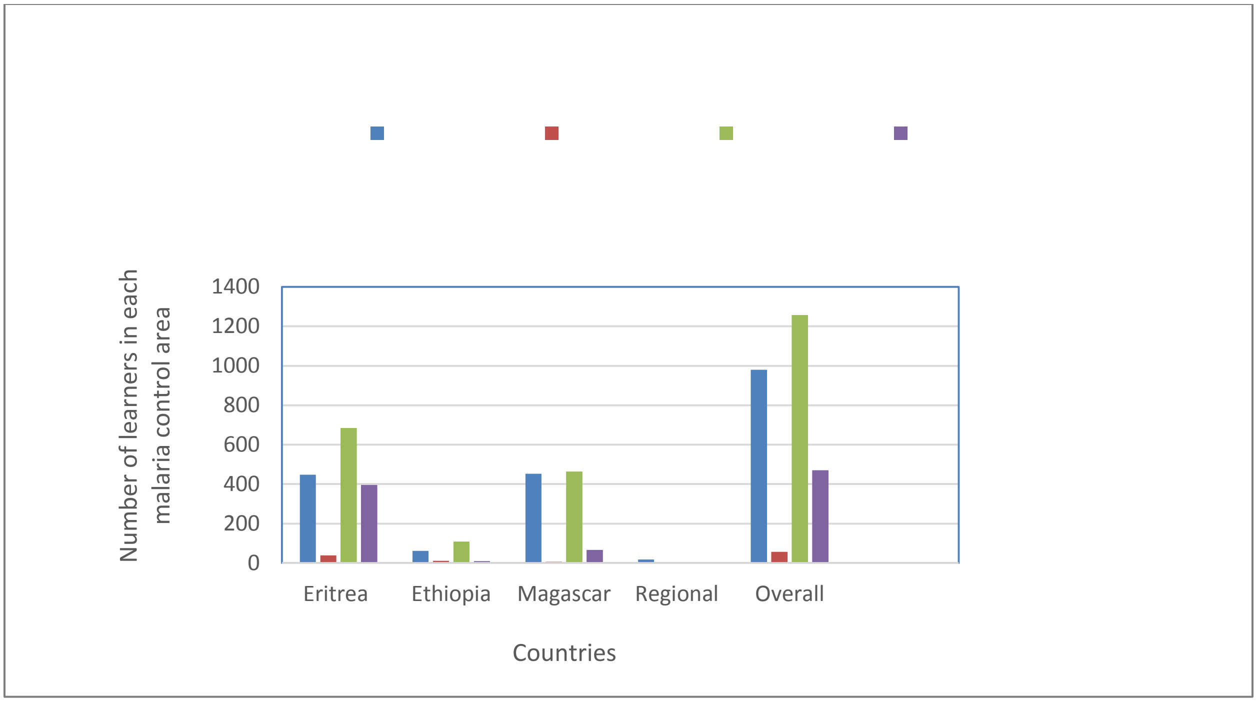


Figure 7: Number of professional and community health workers trained in specific areas of malaria control by project country and at the regional level, 2014–2017

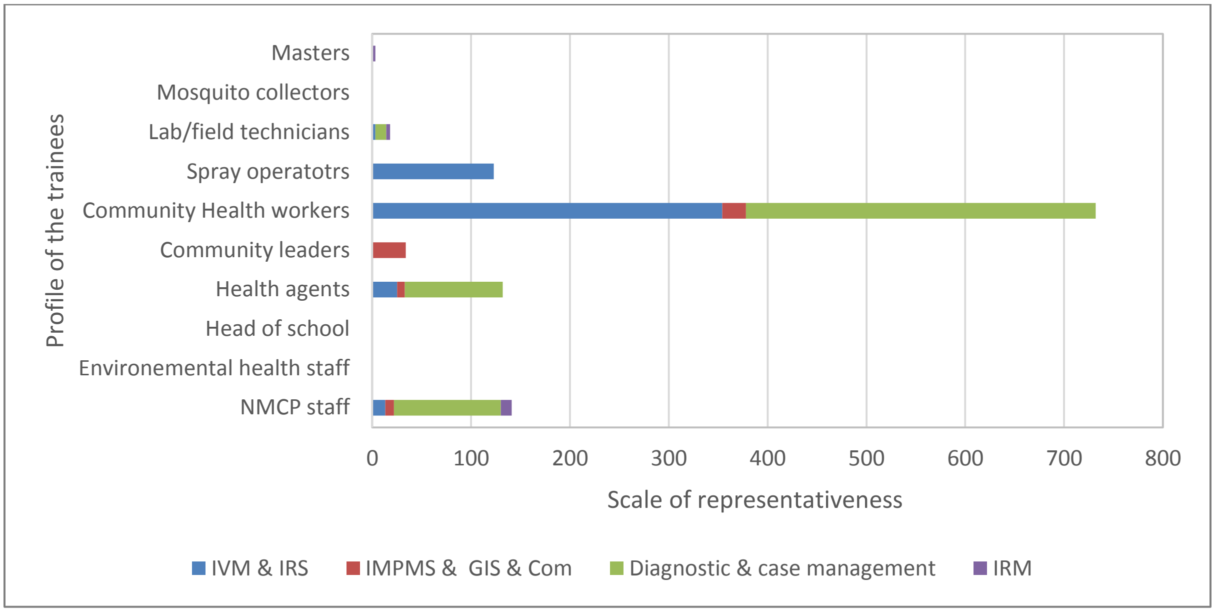


Figure 8: Categories of professional and community members trained in various areas of malaria control, 2014–2017

Expected outcome 2: Health centers are strengthened for emergency situations (e.g., epidemics)

The following indicators were identified for this outcome:

(a) number of health facilities with appropriate antimalarial drugs;

(b) number of malaria cases treated promptly at community level;

(c) number of health professionals trained in malaria diagnosis and treatment;

(d) number of health facilities with adequate capacities for prompt diagnosis of malaria.

Diagnostic tools and antimalarial drugs. To enable prompt response to malaria cases, rapid diagnostic test kits, binoculars, microscopes, motorbikes, and ACT (Coartem) were strategically positioned in all health centres of the project districts. Stocks of supplies were also monitored closely during the project lifespan.

Training. A total of 1,257 learners acquired knowledge in malaria diagnosis and treatment (case management) (Figure 7). This was 14 times higher than was expected (30 health staff per country). The trainees were mostly community health workers, the aim being to increase their involvement in home-based malaria case management. NMCP staff were also trained, along with local health professionals; their responsibility was to plan, implement, and monitor malaria control interventions (Figure 8).

Malaria treatment. The acquired commodities, equipment and knowledge were used to provide prompt treatment to all malaria patients visiting the health facilities in the project districts. In Eritrea, for instance, 25 sub-regions (up from five regions) were earmarked for malaria elimination between 2017 and 2021 [19].

Furthermore, policy, strategic and training documentation was produced by the three countries so as to sustain the efforts deployed for malaria control planning and implementation.

Expected outcome 3: Local communities are equipped with insecticides and application apparatus for dealing with emergencies

Four indicators were identified for this outcome:

(a) Availability of a contingency stocks of DDT at national level;

(b) Availability of trained teams of entomology technicians and sprayers;

(c) Availability of adequate entomological and spray equipment;

(d) Procurement of insecticide and application instruments.

Stocks of DDT. The change of IRS policies in project countries contributed to the interruption of DDT use in malaria vector control. Therefore, no DDT contingency stocks were available for use.

Alternative insecticides, entomological and spray equipment. Stocks of alternative insecticides for emergency preparedness were procured for project districts between 2011 and 2014 (1,329 kg of propoxur to Ethiopia, 1,242 kg of bendiocarb to Madagascar, 2,637 litres and 1,904 litres of pirimiphos-methyl to Madagascar and Ethiopia respectively, etc.). Equipment for entomological monitoring and spray operations was also provided (binocular microscopes, dissecting microscopes, Hudson's sprayers, Haemacue and CDC light traps).

Training. To enhance human resources capacity, 35 entomologists and 458 spray operators were trained in entomology and IRS best practices. The training sessions emphasized the essence of entomological surveillance, including insecticide resistance management in sustaining the programmatic effectiveness of interventions within the context of the IVM strategy.

Expected outcome 4: National referral centres are strengthened and provide technical support to the project and the NMCP

The following indicators were identified for this outcome:

- Availability of well-equipped and operational national referral centres;
- Number of health staff trained in GIS;
- Geo-referenced malaria prevalence and incidence data, information on interventions with environmental and ecological data made available; in health facilities.

Referral centres. Two entomology referral laboratories were strengthened through provision of basic equipment and supplies in Ethiopia and Eritrea. The Aklilu Lemma Institute of Pathobiology, Addis Ababa University, provided support to the Ethiopian NMCP for training in IVM and insecticide susceptibility tests. In Eritrea, inventories of requisite equipment and commodities for the efficient functioning of entomological laboratories were conducted; such inventories inform the procurement process. Three laboratories were made functional in 2016 and sentinel sites were set up in three highly malarious zones, facilitating entomological monitoring.

Staff trained in Geographic information systems (GIS). In the three project countries, a significant number of local health staff (42 instead of 50 which was the end-of-project target) were trained in the use of GIS to collect eco-epidemiological, intervention coverage, and health system data.

Geo-referenced data. Retroactive and prospective data on vector control interventions, epidemiological and entomological profiles were collected in demonstration districts or broadly at country level (Eritrea). These data revealed a progressive decrease in malaria incidence in Eritrea and Ethiopia, but not so clearly in Madagascar as shown in Figure 9.

In Eritrea, IRS was the primary intervention prior to the introduction of ITNs. From 1998 to 2011, DDT was the mainstay insecticide for routine IRS. The country shifted from using DDT for IRS to a rotation of carbamate and pyrethroid in 2012. Yet, the use of LLINs was the main vector control strategy. The LLINs are delivered either through routine free distributions to pregnant women and newborn children or periodic free mass distributions (every three to four years). In 2008 and 2015, ITN and LLIN ownership stood at 70.9% and 88.5%, and the rate of utilization was 47%–49% and 55.1% respectively.

The current national strategic plan for 2015–2019 aims to attain universal coverage through provision of one LLIN for every two persons in every household in the at-risk population, and to ensure at least 80% usage by 2019. Additionally, the NMCP has been deploying larval source management (LSM) as a supplementary intervention to LLINs and IRS. Eritrea has an arid environment and seasonal rainfall patterns, resulting in a limited number of temporary free-standing pools of water that make ideal breeding sites for malaria vectors with predictable locations, thus making LSM an attractive option. Community engagement and participation over the years has been critical in successfully conducting LSM activities, including larviciding using temephos, biological larvicides, and environmental management.

As a result of the combination of malaria control interventions, the malaria burden has declined by 93% over the years from 295,665 cases in 1998 to 20,196 cases in 2015. That said, a sporadic increase was observed between 2008 (22,373 cases) and 2010 (50,725 cases). In spite of this, the same downward trend was seen in annual malaria mortality which fell by 94% from 187 deaths in 1998 to 11 in 2015, followed again by a sporadic increase between 2009 (2 deaths) and 2012 (22 deaths).

Anopheles arabiensis is the dominant malaria vector species in the country. This vector species feeds on either humans or cattle, rests indoors or outdoors, and breeds in temporary rain pools, and hoof prints around the edges of dams and pans. *Anopheles gambiae* s.s. and *An. funestus*, which are known for their high vectorial capacity are also present but at very low frequencies. *Anopheles d'thali, An. cinereus, An. rhodesiensis, An. squamosus* and *An. rupicolus* are considered as secondary vectors. There are marked differences in adult vector behaviour and preferences in larval ecology between these species which impact the ease with which each can be controlled. Earlier studies in Gash-Barka and Anseba showed high vector densities, demonstrating a greater risk of malaria and necessitating strengthened vector control in these zones. However, retroactive data on insecticide resistance profiles were scarce [26].

In Ethiopia, low-lying areas below 2000 metres in altitude and high temperate zones are the most malarious. Short-lived severe epidemics generally occur immediately after the long rains in September to November and in some areas also after the short-lived rains in February to April. Vector control interventions are largely based on IRS and ITNs in combination. IRS, mainly with DDT, has been implemented in the country since 1959. Concerted efforts by the Ministry of Health and its partners have had a significant impact on malaria.

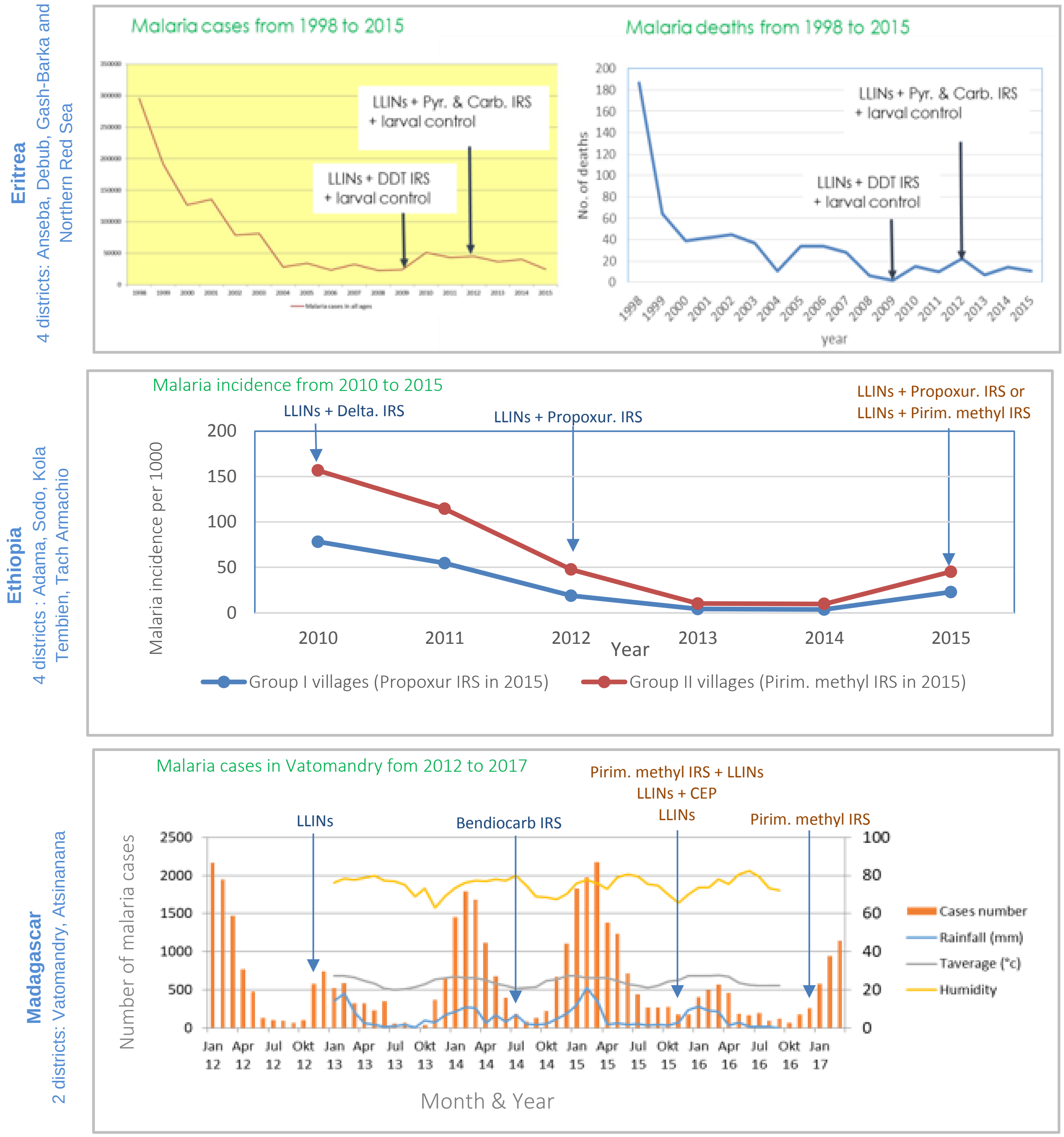


Figure 9: Trends in malaria incidence in Eritrea, Ethiopia, and Madagascar, 1998–2017

(Pyr: pyrethroid; Carb: carbamate; Pirim: pirimiphos)

Retroactive and prospective data revealed heterogeneity of annual malaria incidence in 2010, varying from 78‰ to 157‰ between the two clusters of localities selected for demonstration of alternatives (Figure 9). From 2010 to 2014, incidence progressively declined to less than 11‰ in the two clusters while DDT had not been used for IRS in Ethiopia since 2009. However, in 2015, incidence increased again to 23‰ and 45‰ in Cluster I (sprayed with propoxur) and Cluster II (sprayed with pirimiphos-methyl) respectively. *Anopheles arabiensis* was identified as the main malaria vector species in Ethiopia. The current national malaria strategic plan for 2014–2020 aims to provide all Ethiopians with access to quality, equitable and effective malaria control services, with emphasis on community empowerment, mobilization, and ownership.

In Madagascar, IRS and nationwide distribution of LLINs are the main vector control interventions. LLINs are allocated either through routine free distributions to pregnant women and newborn children or periodic free mass distributions. In 2011, malaria deaths were estimated at 5% to 19% of cases, with variations from one district to another. From 2012 to 2017, four major series of vector control interventions were implemented in the project district of Vatomandry. The series of interventions included an LLIN free distribution campaign in November 2012, bendiocarb IRS in July 2014, pirimiphos-methyl IRS and LLIN free distribution (or LLINs + community education and participation, or LLINs alone) in November 2015 and pirimiphos-methyl IRS in December 2016 (Figure 9).

Retroactive and prospective epidemiological data collected in demonstration communes revealed huge seasonal variations in the number of malaria cases during a given year as well as from one year to another. The highest prevalence was recorded between November 2014 and June 2015 during the rainy season (≈2,200 cases in March 2015) and the lowest between July and October 2013 during the dry season (5 cases in August 2013). During high transmission seasons in 2012 and 2016, the peaks of malaria cases drastically declined following the wide distribution of LLINs combined with or without pirimiphos-methyl IRS operations (i.e., <800 cases in December 2012 and March 2016), compared with the peaks in February 2014 (≈1,800) and March 2015 (≈2,200 cases).

Anopheles funestus, *An. gambiae s.l.* and *An. mascariensis* are the main malaria vectors in Madagascar. Data collected from November 2012 to February 2013 (i.e., during the high transmission season) revealed temporal variations in vector biting rates according to each species (Figure 10). In Mangiboka Village for instance, the per-person biting rates decreased from 5.65 bites/person per night (in November) to 0.5 bites/person per night (in February) for *An. gambiae s.l.* However, biting rates increased from 0.125 bites/person per night (in November) to 1.35 bites/person per night (in February) for *An. funestus*, or from 0.3 bites/person per night (in November) to 2 bites/person per night (January), followed by a decrease to 0.5 (in February) for *An. mascariensis*. *An. pauliani, An. squamosus,* and *An. coustani* are also present but are considered as secondary vectors based on their sporadic role in malaria transmission.

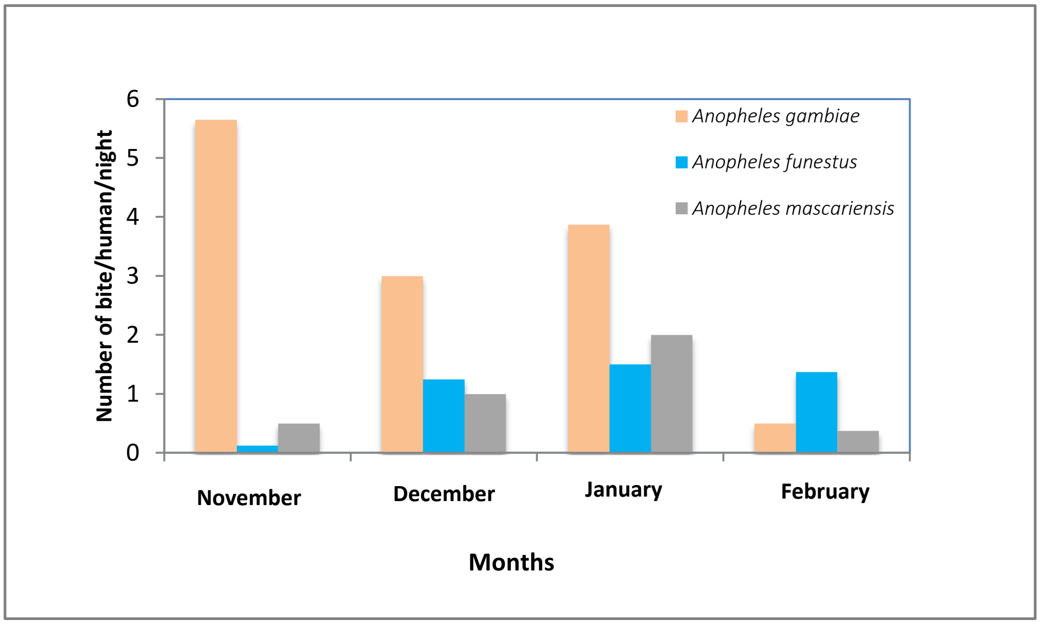


Figure 10: Monthly variations in per-person biting rates by anopheles malaria vector species in Mangiboka Village, Vatomandry District, Madagascar (November 2012–February 2013)

Expected outcome 5: Community awareness is raised about alternative interventions and less dependence on DDT

Countries took different approaches to strengthening community involvement and to raising awareness about alternative malaria control strategies and tools in the framework of IVM.

In Eritrea, an IVM stakeholder consensus and information dissemination workshop was held in 2017 to review the national strategic plan for malaria and to reach consensus on the establishment of viable sectoral collaboration on IVM [20]. The workshop resulted in the development of strategies for collaborative work, on weather forecasting and epidemic preparedness, awareness about the advantages of alternative interventions, and how to minimize dependence on DDT for malaria vector control.

In Ethiopia, an anthropological survey was conducted in selected districts from October to December 2016 in order to:

(a) assess the overall implementation of iec/ bcc interventions for malaria prevention and control in the country, particularly in gef project sites;

(b) identify best practices, challenges and gaps for future improvements in community awareness interventions using IEC/BCC materials in the project areas.

Data were collected through a review and assessment of relevant documentation at the various levels, and qualitatively from focus group discussions and key informant interviews. Overall, several weaknesses were revealed after an analysis of IEC/BCC for malaria prevention and control in Ethiopia. The main finding was 'the insufficiency of IEC/BCC activities for education and sensitization of schools, public health workers, and communities (including migrant workers and pastoralists) about the benefits of IRS, LLINs and environmental sanitation' (Table 4). Subsequently, a number of actions were taken for the formulation of a national IEC/ BCC strategy aimed at raising community awareness about the replacement of DDT by alternative chemicals in malaria control in Ethiopia.

Major strengths that were identified included:

(a) a supportive policy environment with strong leadership and commitment to integrate malaria prevention in health communication;

(b) a functional technical working group on health education and communication (HEC-TWG) that serves as a platform for coordinating and fostering partnerships, as well as harmonizing and aligning health promotion and communication interventions for disease control, including control of malaria;

(c) strong commitment and leadership in engaging and encouraging communities to participate in health promotion and disease (including malaria) prevention at the household level;

(d) supportive polices such as expansion of health infrastructure at all levels and promotion of the development of all categories of health care providers in sufficient numbers to ensure access and quality of care and enable the attainment of nationally and globally set health promotion targets ;

(e) the upward trend in documentation and dissemination of best practices in health promotion and disease (including malaria) prevention;

(f) the increasing use of ICT and the internet for sharing information and exchanging IEC/BCC messages.

Table 3: Situation of IEC/BCC for malaria vector control in Ethiopia in 2016

Situation of IEC/ BCC for malaria vector control in 2016	Actions needed to raise community awareness about replacement of DDT by alternatives in malaria control
(a) Limited IEC/ BCC activities for education and sensitization of schools, public health workers, and communities (including migrant workers and stockbreeders) about the benefits of IRS, LLINs and environmental sanitation. (b) Very low community awareness about the need for replacement of DDT by alternative chemicals in IRS. (c) Inadequate or unavailable IEC/BCC materials on malaria prevention and control interventions. (d) Weak collaboration between the health, education, and agriculture sectors. (e) Poorly structured IEC and lack of trained staff for malaria prevention and control, leading to ineffective delivery of messages on the subject to the communities. (f) Inadequate funding and resources for multisectoral activities. (g) Low involvement of media outlets and mini-media in schools and of local FM radio in the fight against malaria. (h) Absence of clear guidelines and an appropriate environment for disposing of wastes and obsolete chemicals and promoting environmental sanitation. (i) Haphazard involvement of community and political leaders in malaria campaigns. (j) Adverse effects following IRS operations not reported or documented.	(a) Intensify focused IEC activities on the promotion of LLINs and IRS with alternative chemicals replacing DDT in all socio-political and cultural groups, especially those living near irrigation sites. (b) Increase community knowledge of, and participation in, IRS, LLINs and environmental sanitation operations. (c) Educate and sensitize the public, households and health extension workers about replacement of DDT prior to IRS operations, e.g., during preparation of alternative templates. (d) Train health workers on malaria prevention and control, emphasizing the replacement of DDT by alternative chemicals. (e) Use radio, TV and IEC materials to increase community awareness about alternatives to DDT before, during, and after IRS operations, LLIN ownership, or environmental sanitation campaigns. (f) Provide IEC/BCC materials to schools and other population groups. (g) Develop a local community conversation (CC) strategy to build knowledge about malaria and its prevention methods. (h) Target IEC/BCC messages at IRS operators encouraging them to remove and dispose of obsolete chemicals, plastic containers and personal protection equipment, as well as report any adverse effects following IRS operations. (i) Intensify collaboration between the education, health and agriculture sectors and share best practices and strategies for resource mobilization.

In Madagascar, the anthropological study conducted in January 2013 showed that the community was deeply engaged in the fight against malaria. The approach to raise their awareness about alternative malaria control methods, therefore, focused on the development of their participatory leadership, given that the community already recognized the effectiveness of their preventive vector control arsenal that includes IRS, LLINs and larval control. Moreover, despite a high rate of illiteracy in some areas, the country does have opportunities to disseminate IEC messages through pre-school and school institutions based on experience gained from the project for sustainable community mobilization. Community awareness about malaria transmission and locally appropriate preventive and curative methods was raised through IEC and BCC activities comprising 84 talks, 269 mass sensitization campaigns, 22 group discussions and 17 home visits. The total number of participants in these activities was 7,423; the breakdown by channel of communication is provided in Figure 11. The NMCP was encouraged to develop a functional literacy programme and training modules for (a) administrative and traditional community leaders; (b) community health workers; (c) adult populations; and (d) school teachers.

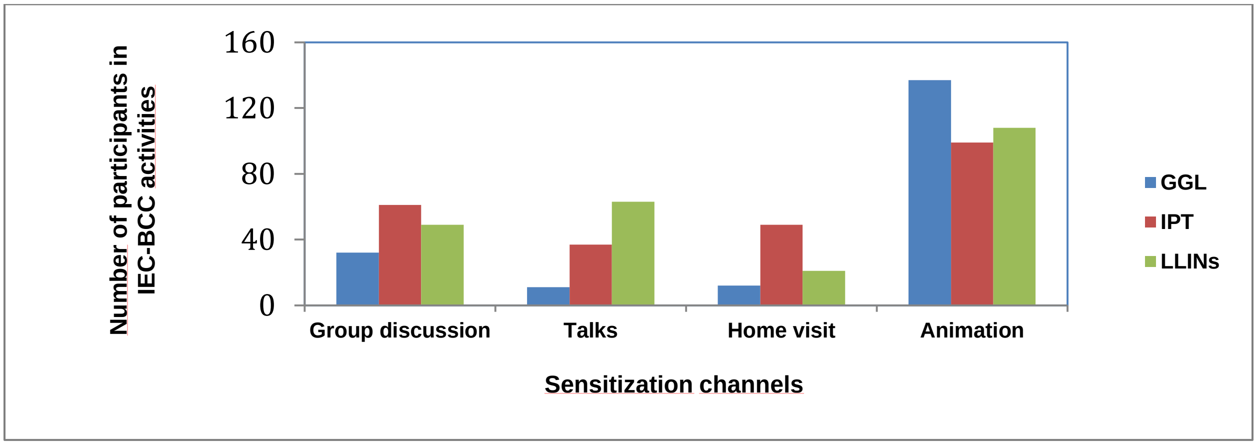


Figure 11: Outcomes of IEC and BCC activities to raise community awareness about alternative interventions and reduced dependence on DDT in Madagascar, 2013–2015

Expected outcome 6: Integrated malaria monitoring and surveillance system developed and implemented

The indicator that was identified for this outcome was the evidence that malaria cases were notified weekly to the national malaria control programmes and logged into the MIS database. This target was achieved in Ethiopia where cases were notified weekly to the district health offices by the health posts. In Madagascar the cases were notified monthly by health centres to the districts. In Eritrea, health facilities reported cases to districts on a weekly basis. However, data were collected from routine national malaria information systems (MIS). No separate MIS data were collected for project districts.

COMPONENT 2: Implementation of alternative methods of malaria vector control tailored to local circumstances

Under this component, countries put in place the strategies and resources they need to implement alternatives as follows:

(a) Collection and analysis of up-to-date epidemiological and entomological data for timely and appropriate application of alternative interventions;

(b) Implementation of alternative strategies tested for viability, applicability and cost-effectiveness under local conditions;

(c) Evaluation of community participation using locally developed indicators on behavioural impact;

(d) Conduct a risk assessment of alternative insecticides.

The implementation of alternative strategies under local conditions was mainly based on the combination of LLINs at high coverage with IRS using lambda-cyhalothrin (pyrethroid), pirimiphos-methyl (organophosphate) or propuxur (carbamate) insecticides. Replacement of DDT in IRS took place in 2012 in Eritrea, in 2010 in Ethiopia, and before 2009 in Madagascar (Figure 9), depending on preparedness of the country and availability of the alternative chemicals. In Eritrea, LLINs and IRS were complemented by larval source management. Community participation in the change of IRS policies and risk assessment were found to be very weak; countries, therefore, designed strategies to raise community awareness and effect compliance with alternatives, especially in Madagascar and Ethiopia where IEC and BCC activities for malaria vector control were not documented before the project.

In Ethiopia, pirimiphos-methyl was the alternative insecticide selected for the implementation of the current project. Madagascar used bendiocarb (2014) and pirimiphos-methyl (2015 and 2016) in different IRS rounds. To evaluate the impact of changing the IRS strategies, prospective parasitological information, health facility case reports, and entomological data were collected from 2010 to 2015. Data collected before 2012 in Eritrea or before 2015 (prior to pirimiphos-methyl IRS) were considered as baseline, while those gathered afterwards were considered as post-intervention outcomes. Country-specific data are presented in the sections that follow.

Expected outcome 1: Integrated malaria monitoring and surveillance system developed and implemented

Six of the ten selected project districts have up-to-date parasitological and entomological data, including data on insecticide resistance. Ethiopia has data on anaemia as well.

Eritrea

Malaria transmission in Eritrea is now confined to certain regions or sub-regions. In 2013, Eritrea met the strategic threshold needed to transition from control to elimination.

(a) Parasitological data

Parasitological data were collected from 2011 to 2015. A map showing malaria incidence in all regions and sub-regions was produced (Figure 12). There was marked geographical heterogeneity in malaria incidence between regions and within subregions. For instance, in Anseba Region, incidence varied from 0.3‰ in the Adi-tekelezan Subregion to 18‰ in the Sel'a Subregion. The malaria burden has declined over the years from 45,000 cases in 2012 to 20,196 cases in 2015. The same downward trend was seen in annual mortality from malaria which fell from 20 deaths in 2012 to 11 deaths in 2015. The Gash-Barka and Debub regions contributed more than 80% of malaria cases. The number of malaria cases in Gash-Barka Region was estimated at 13,000 out of over 20,196 cases recorded nationwide (Figure 13). In 2012, national

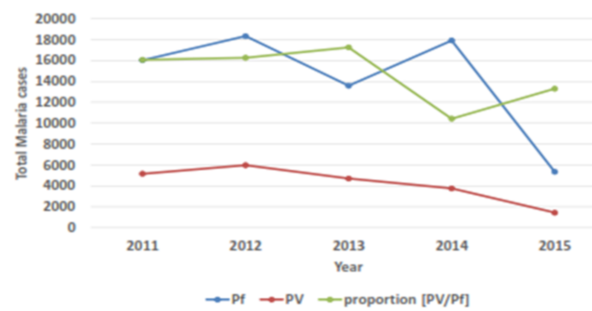


Figure 12: Proportion of *Plasmodium falciparum* and *P. vivax* in the Gash-Barka Region (Eritrea) (2011–2015)

malaria parasite prevalence was 1.9% using rapid diagnostic tests and 1.1% using microscopy based on positive cases at health facilities. Cases ranged from 0.4% in Anseba and Northern Red Sea to 3.8% in Gash-Barka. There was a drop in the number of malaria cases from 2012 to 2015; the drop was associated with a significant downward trend in both *P. falciparum* infections (from >35% in 2012 to ≈10% in 2015) and *P. vivax* infections (from ≈12% in 2012 to <5% in 2015). In Gash-Barka Region, the number of cases declined from ≈16,000 to ≈13,000 for both *P. falciparum* and *P. vivax* during the same period (Figure 13).

(b) Therapeutic efficacy testing

A 28-day therapeutic efficacy study of AS-AQ, the first-line medicine for the treatment of uncomplicated *P. falciparum* malaria, was conducted at four sites in Gash-Barka Region in 2016. Results showed 93.5% efficacy and supported the continued use of AS-AQ in Eritrea.

(c) Malaria vectors and transmission

In December 2016, *Anopheles* larvae and adults were collected from five villages of Mendefera and Dubarwa sub-zones and 8 villages in the Zoba Debub sub-zones. Larvae were reared to adult stage and used for morphological identification. *Anopheles gambiae s.l.* (mainly *An. arabiensis*) and *An. cinerius* were the predominant vector species in most of the villages in the Mendefera and Dubarwa sub-zones (57%–92.7%) and the Zoba sub-zone (57%) respectively (Figure 14). *An. gambiae* s.s., *An. pretoriensis* and *An. dimellion* were also present in the same villages, although at lower frequencies (0%–19%). However, none of the 264 adult *An. gambiae s.l*. collected indoors in Zoba Debub were positive for *P. falciparum* sporozoites.

(d) Insecticide resistance monitoring

Wide heterogeneity was observed in the profile of *An. gambiae s.l*. resistance to 10 insecticides surveyed in 2012 across six geo-locations in four malarious zones, using WHO susceptibility testing (Figure 15). The data presented in Figure 16 revealed a wide distribution of resistance to organochlorine and pyrethroid insecticides (41%–88% mortality rate), while tested samples were mostly susceptible to organophosphate and carbamate insecticides (98%–100% mortality rate). Furthermore, all the samples analyzed by polymerase chain reaction (PCR) carried kdr 1014F resistance allele.

(e) Bio-efficacy of bendiocarb in IRS

The residual bio-efficacy of bendiocarb in IRS against *An. gambiae* s.l. samples collected from Tesseney, as tested using the WHO cone assay in 10 selected sprayed houses, was very low. The overall mortality rate of mosquitoes 24 hours after exposure to bendiocarb-sprayed walls 55–75 days after spray operations, was 39%.

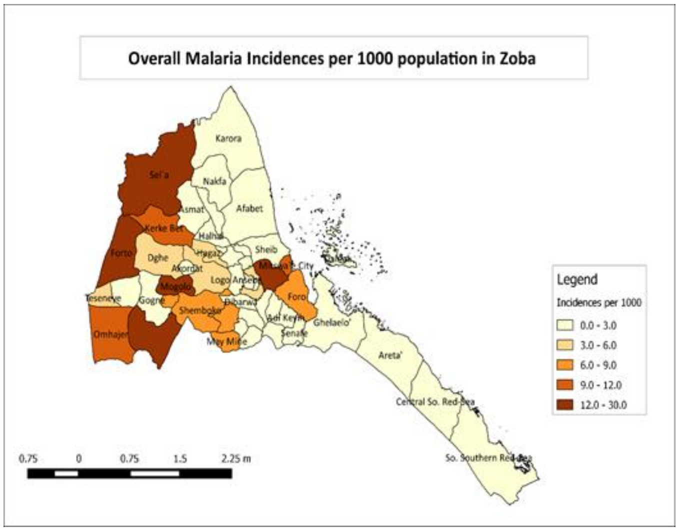
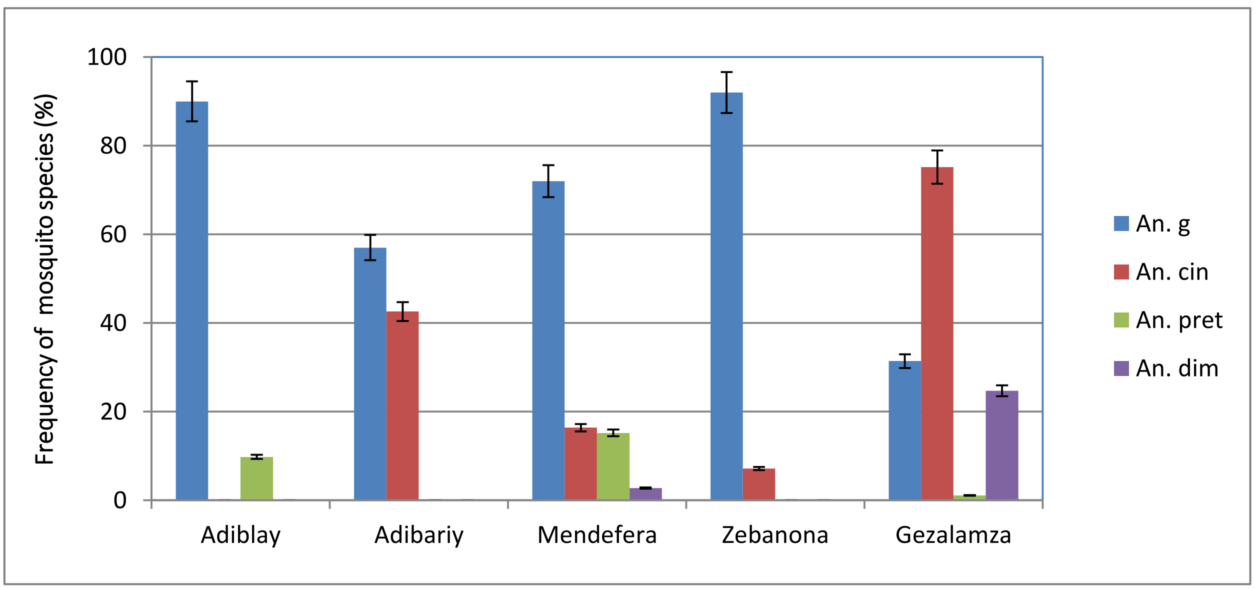


Figure 13: Map showing malaria incidence in Eritrea in 2015

A.



B.

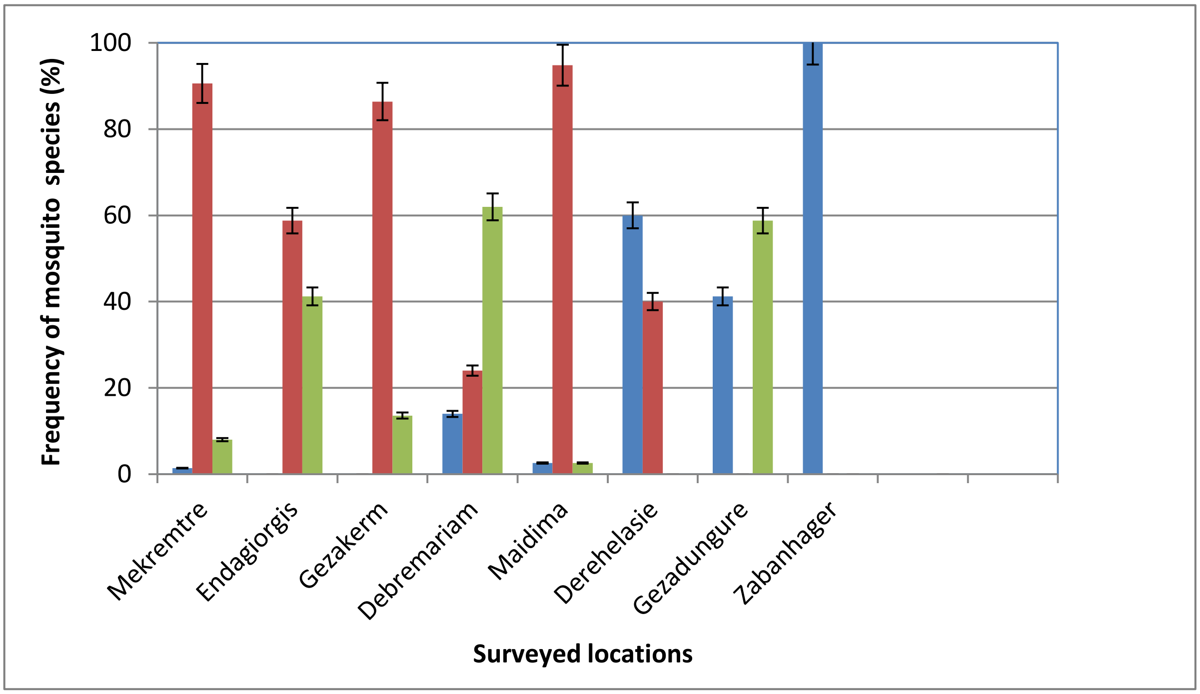


Figure 14: Species composition of *Anopheles* samples from five sites in the Mendefera and Dubarwa sub-zones (A) and eight sites in the Zoba Debub sub-zone (B) (Eritrea).

(An. g: Anopheles gambiae s.l.; An. cin: Anopheles cinereus; An. pret.: An. pretoriensis; An. dim: An. dimellion)

Figure 15: Insecticide resistance testing in Mendefera, Debud zone, Eritrea

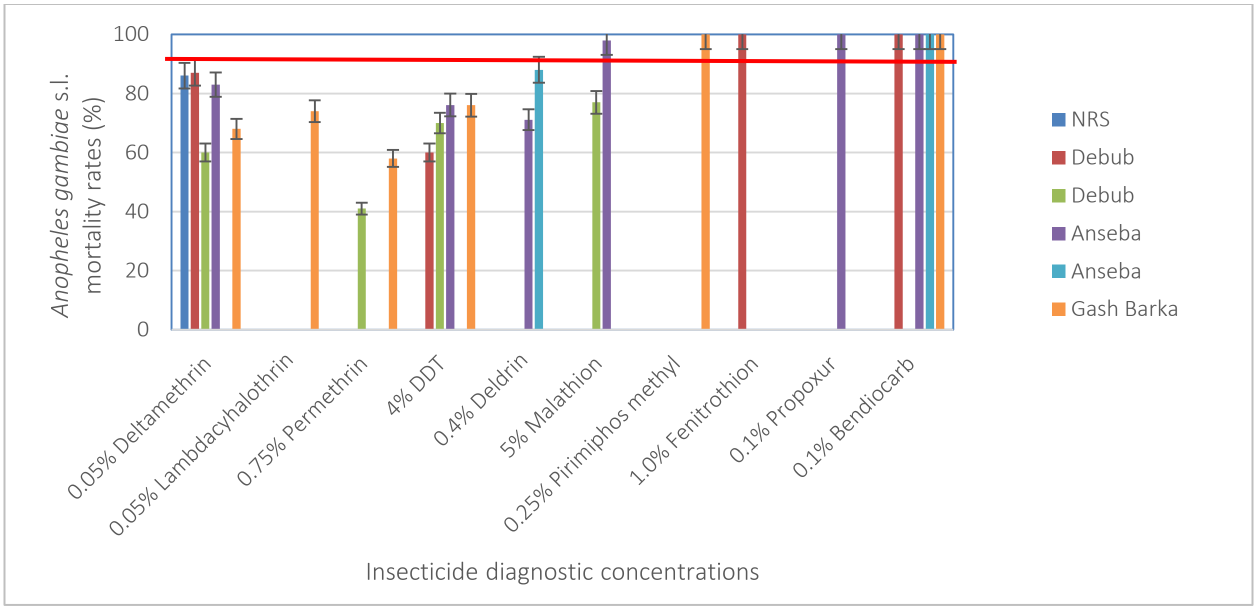


Figure 16: Status of *An. gambiae s.l.* resistance to insecticides in four malarious zones of Eritrea in 2012

Status was determined based on the use of standard WHO insecticide susceptibility bioassay. The red line at 90% mortality rate indicates the threshold of confirmed resistance in the tested mosquito population.

Ethiopia

Parasitological and entomological data were collected each year from 2012 to 2015, between September and December. The data collected in 2012, 2013, and 2014 were considered as baseline data while those gathered in 2015 following spraying with pirimiphos-methyl were considered as post-intervention outcomes. Two groups of villages were established as follows: Cluster I comprising four localities (Frishi, Merebie Mermersa, Masero and Workamba) where propuxur was used for IRS and Cluster II comprising four localities (Adazer, Bate Germame, Asherie and Guya) where pirimiphos-methyl was used for IRS (Figure 17).

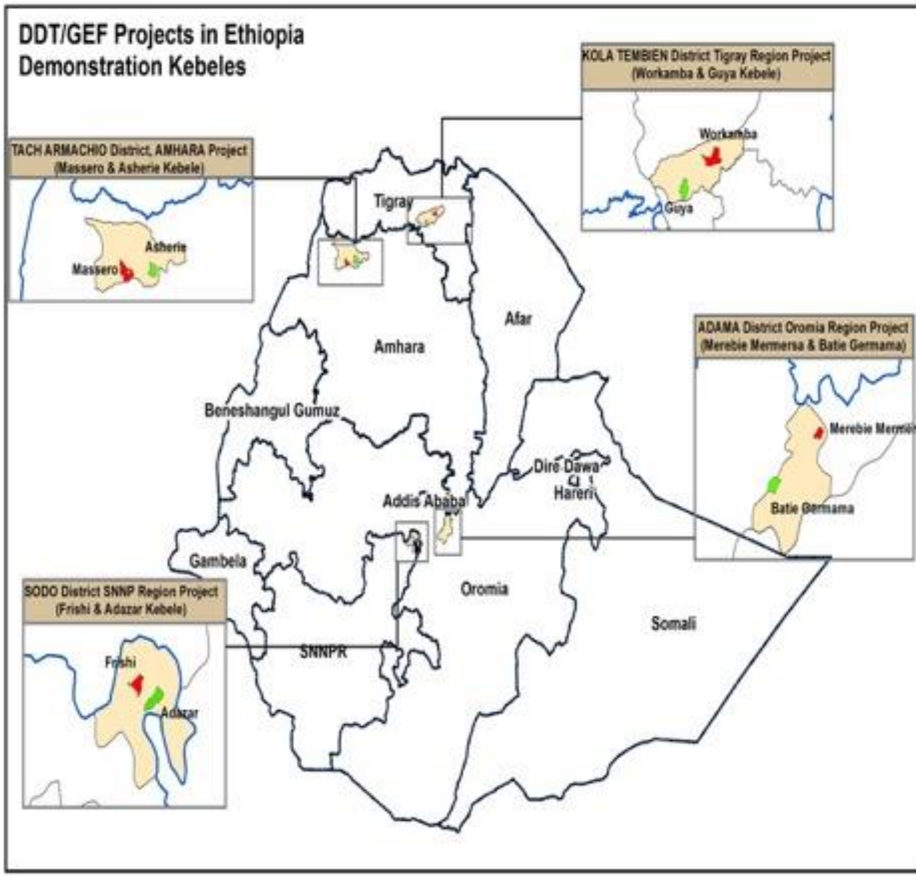


Figure 17: Map of Ethiopia showing the location of project districts

(a) Parasitological and anaemia data

Parasitological and anaemia data were collected through microscopic examination of thin and thick blood films. In 2012, malaria parasite prevalence was 10.35% and 13.6% in Cluster I and Cluster II localities respectively (Figure 18). From 2012 to 2015, the prevalence progressively declined to below 0.2% in the two clusters. No significant difference was seen between the localities where dwellings were sprayed with propoxur and those sprayed with pirimiphos-methyl in 2015. However, the rate of anaemia declined from 10% to 5.4% only in Cluster I localities that were sprayed with propoxur in 2015. In Cluster II localities, the rate of anaemia remained unchanged and ranged from 9% to 10.5% (Figure 19).

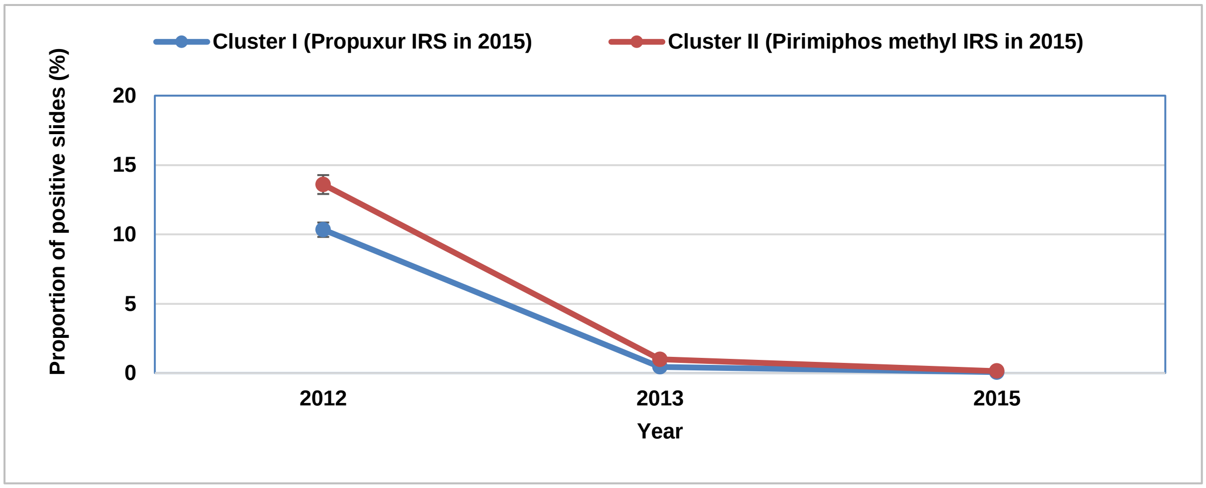


Figure 18: Malaria parasite prevalence in study populations from two clusters of localities in Ethiopia, 2012–2015

(Clusters are differentiated by the insecticides used for IRS in each of them)

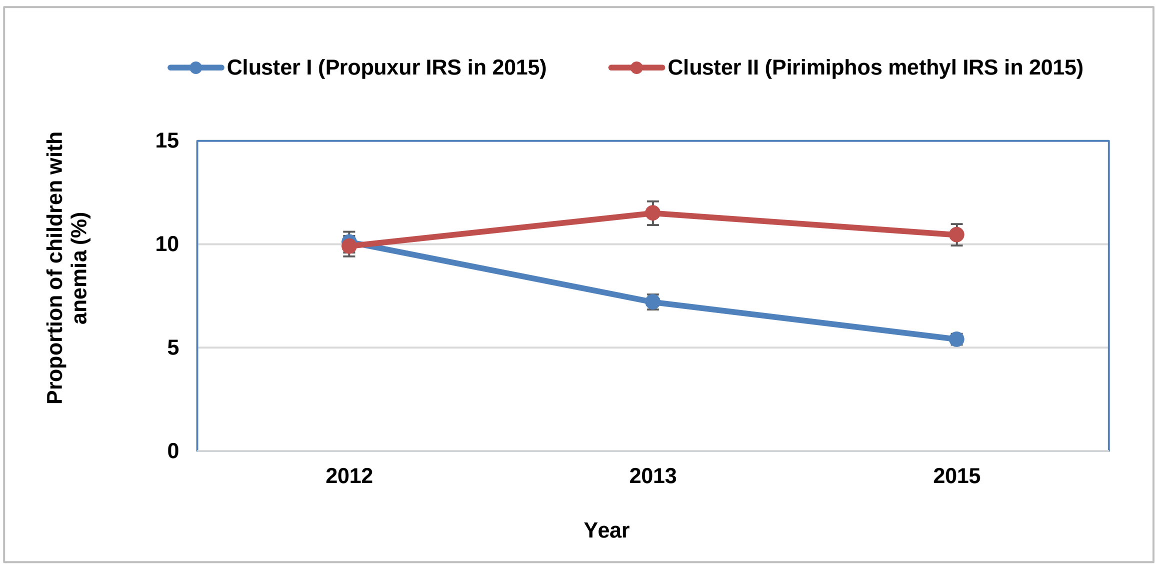


Figure 19: Proportion of anaemia in study populations from two clusters of localities in Ethiopia, 2012–2015.

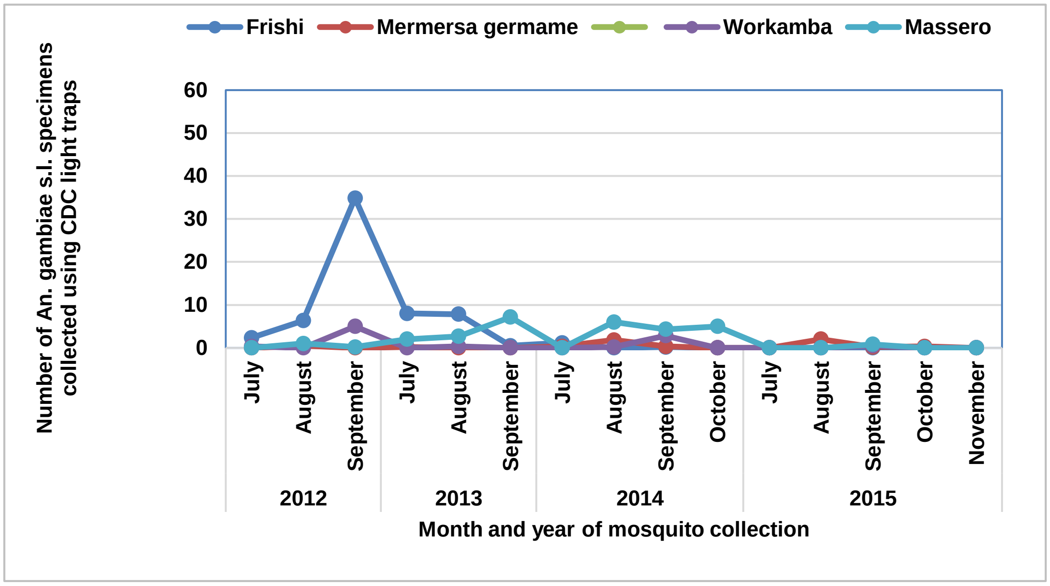
(Clusters are differentiated by the insecticides used for IRS in each of them).

(b) Malaria vectors and transmission

Mosquitoes were collected indoors using CDC light traps (68.1% of specimens collected), pyrethrum spray catches (PSC) (28.5%) as well as window exit traps (3,2%). A total of 4,755 mosquitoes belonging to four species, species complexes or groups were collected. These included *An. gambiae* s.l. (mainly *An. arabiensis*) (96.8%), *An. pharoensis*, *An. funestus* group, and *An. demilloin* (3.2% for the three species). A decline of *An. gambiae s.l.* density was recorded across all the demonstration localities after IRS intervention in August 2015. In Cluster I locallities which were sprayed with propoxur, the annual peaks of *An. gambiae s.l.* density decreased from 5–35 specimens/night per room in 2012 to less than 0.8 specimens/night per room in 2015 (Figure 20). The same trend was observed in two localities in Cluster II (Adazer and Guya) which were sprayed with pirimiphos-methyl. However, in the two remaining localities in Cluster II (Bate Germame and Asherie), the peaks of *An. gambiae s.l.* density did not decrease before 2015. A decrease was instead observed during the high transmission period in 2015; vector density during that period was null in Asherie while decreasing from 29 specimens/night per room to zero in Bate Germame.

The gonotrophic status of *An. gambiae s.l.* specimens collected by the PSC method revealed that most of the mosquitoes resting indoors were either unfed or freshly fed (Figure 21). This pattern had been consistent over the years. In Cluster I localities, the proportion of fed specimens was significantly higher in 2012 and 2013 (60%–67%), compared with unfed mosquitoes (33%–40%) ($p<0.0001$). In 2014, the proportion of fed mosquitoes dropped to 35%, suggesting that vector control interventions during that period significantly reduced mosquito blood feeding ($p<0.0001$). The same trend was observed in Cluster II localities in 2013 and 2014, when propoxur IRS was implemented in those localities. However, in 2015, no significant difference was observed between the proportions of fed and unfed specimens.

A.



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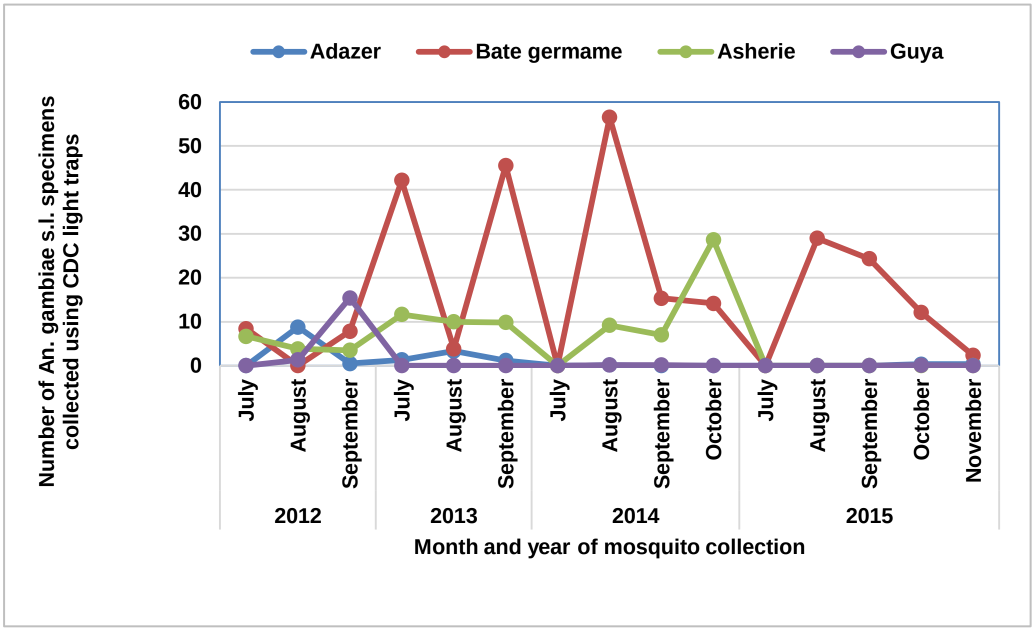


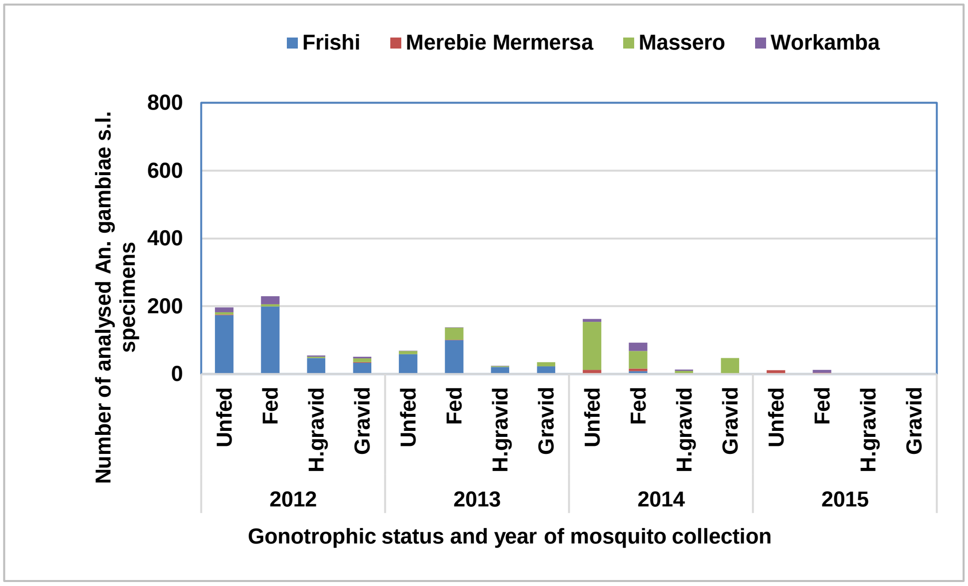
Figure 20: Dynamics of *An. gambiae* s.l. populations in demonstration sites in Ethiopia (2015)

(A. Cluster I localities (Frishi, Merebie Mermersa, Massero and Workamba) where propuxur was used for IRS in August 2015; B. Cluster II localities (Adazer, Bate Germame, Asherie and Guya) where Pirimiphos-methyl was used for IRS in August 2015)

(c) Insecticide resistance monitoring

Using WHO susceptibility assay, diverse profiles of insecticide resistance were recorded in the four *An. gambiae s.l.* populations from pilot districts tested in 2015. Resistance to DDT, deltamethrin, lambda cyhalothrin and malathion was widespread (1%–78% mortality rate), while tested samples were mostly susceptible to fenitrothion, pirimiphos-methyl and propoxur (98%-100% mortality rate) (Figure 22). Various profiles of resistance to malathion and bendiocarb were recorded, with mortality rates ranging from 33% to 100%. Very few data on the status of vector susceptibility to pirimiphos-methyl and propoxur were reported. Both insecticides were used for IRS in Ethiopia while pirimiphos-methyl and bendiocarb were used in Madagascar.

A.



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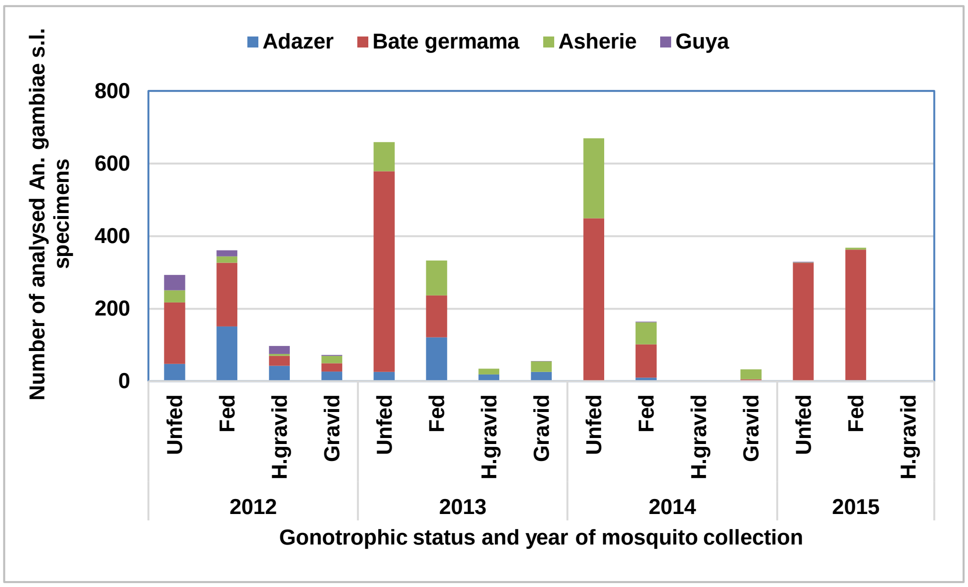


Figure 21: Profile of the gonotrophic status of *An. gambiae s.l.* populations in demonstration sites in Ethiopia, 2012–2015

(A. Cluster I localities (Frishi, Merebie Mermersa, Massero & Workamba) where propuxur was used for IRS in August 2015; B. Cluster II localities (Adazer, Bate Germame, Asherie & Guya) where Pirimiphos-methyl was used for IRS in August 2015)

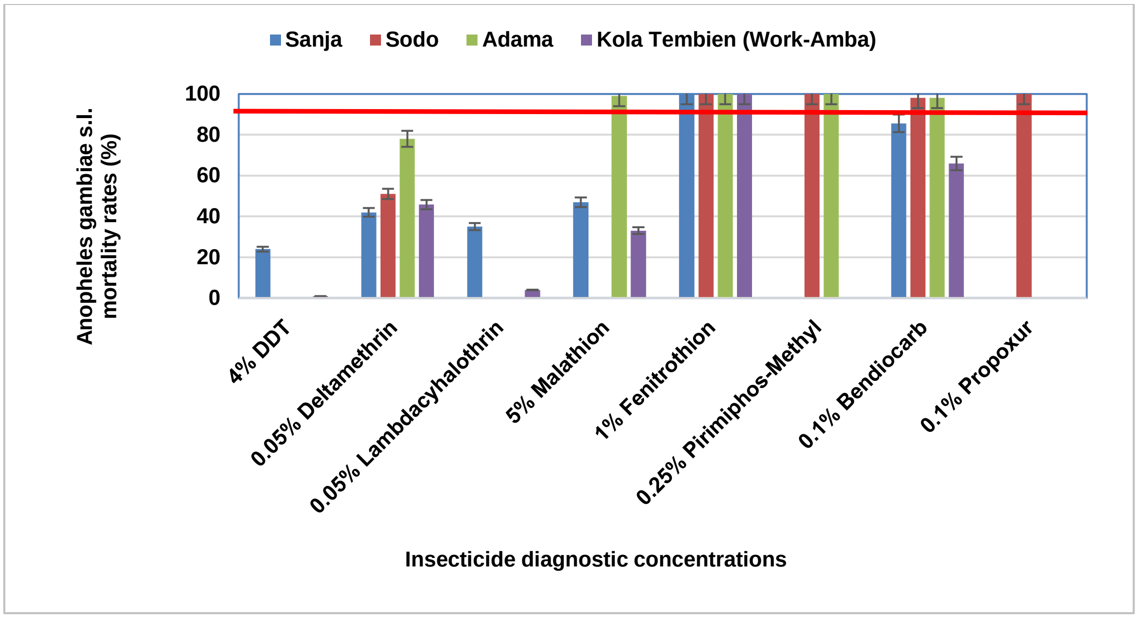


Figure 22: Status of *An. gambiae s.l.* susceptibility to insecticides in the demonstration districts in Ethiopia (2015)

(The red line at 90% mortality rate indicates the threshold of confirmed resistance in the tested mosquito population. Standard WHO insecticide susceptibility bioassays were used)

(d) Residual bio-efficacy of pirimiphos-methyl on sprayed walls

The bio-efficacy of pirimiphos-methyl on sprayed walls (mostly on mud) in Adama and Sodo districts decreased from 93.25%–100% in September 2015 just after spray operations to 40.8%–74.17% in November 2015 (Figure 23). This mortality rate three months post intervention was below the threshold of IRS efficacy.

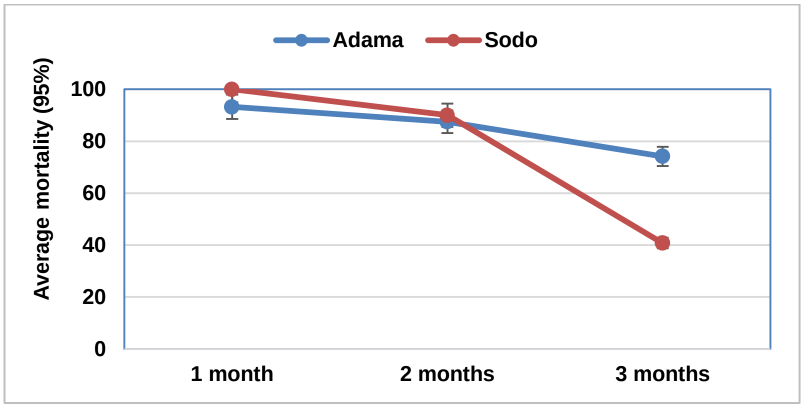


Figure 23: Residual bio-efficacy of pirimiphos-methyl applied in houses against susceptible *An. gambiae* at 1–3 months post intervention in Ethiopia based on WHO cone bioassay tests (2015).

Unfortunately, no comparative measurements for propoxur were available.

Madagascar

Variations in parasitological and entomological parameters after implementation of three different combinations of alternative interventions were assessed in the three study arms as follows: (a) LLINs alone; (b) LLINs + pirimiphos-methyl IRS; and (c) LLINs + community engagement and participation. Ten sentinel sites randomly selected from the three intervention arms within the four communes of Vatomandry District were monitored.

(a) Parasitological data

Monthly malaria incidence was collected from the health facilities from 2013 to 2017. Malaria infection prevalence (regardless of fever) was recorded based on cross-sectional surveys conducted once a year during high transmission seasons, using the Pf/pan rapid diagnostic test.

In each of the three study arms, malaria incidence per 1,000 varied in a bell-shape (Figure 24). It increased from 2.2‰, 1.4‰ and 1.7‰ in 2013 to 5.5‰, 10.2‰ and 7.0‰ in 2015 for the LLINs, LLINs + CEP and LLINs + IRS arms respectively. Following the interventions, incidence progressively declined over time to less than 3‰ in 2017 in the three arms. The highest impact was recorded in the LLINs + CEP and LLINs + IRS arms, where incidence was down 41 and 24 times respectively, compared with a four-fold drop in malaria incidence in the LLINs arm.

In 2013, infection prevalence was lower in the LLINs arm (7%), compared with the rates in the other two arms (69%–70%). From 2013 to 2017, it progressively declined in the three arms to 2%–3% in 2017 (Figure 25). The steepest decline was recorded in the LLINs + CEP and LLINs + IRS arms (4–8 times reduction compared with a three-fold drop in the LLINs arm).

(b) Entomological data

The density of the three major malaria vectors (*An. gambiae s.l*, *An. funestus* and *An. mascariensis*) was monitored monthly during high and low transmission seasons. In 2013, biting rates in the three demonstration arms were less than 0.01 bites/person per night for the three vector species (Figure 26). However, these rates progressively increased after 2013. The highest rates were recorded in the LLINs + IRS arm in 2016, despite the fact that two cycles of pirimiphos-methyl IRS were conducted in November 2015 and December 2016 respectively. The per-person biting rates during that period were 0.1, 0.4 and 0.6 bites/person per night for *An. mascariensis*, *An. funestus* and *An. gambiae s.l* respectively. The lowest rates were recorded in the LLINs arm, with less than 0.15 bites/person per night for each of the three vector species.

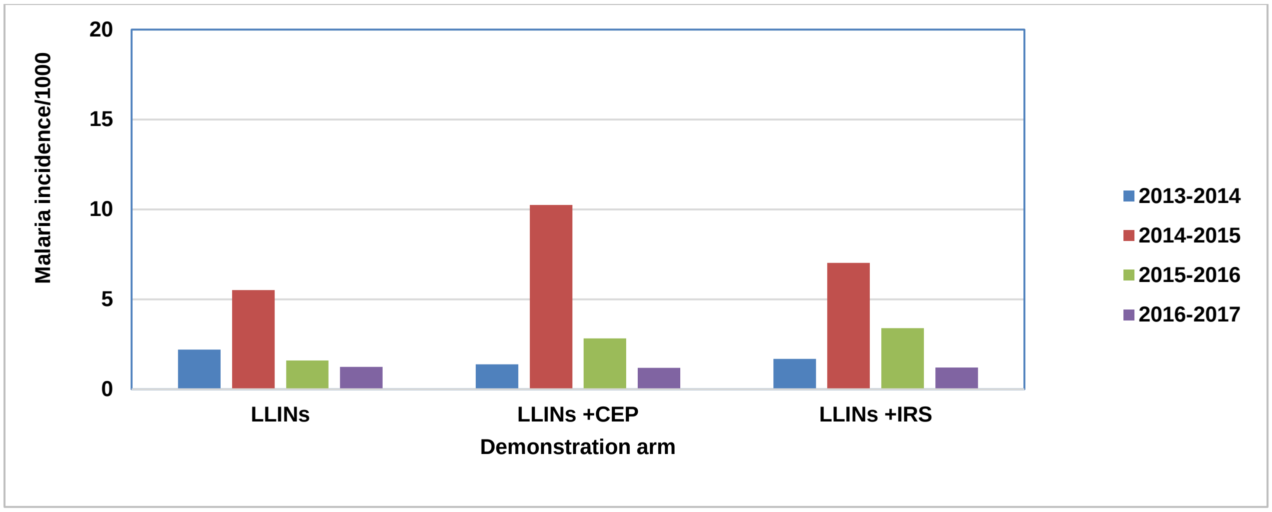


Figure 24: Variations in malaria incidence in Vatomandry District, Madagascar, 2013–2017

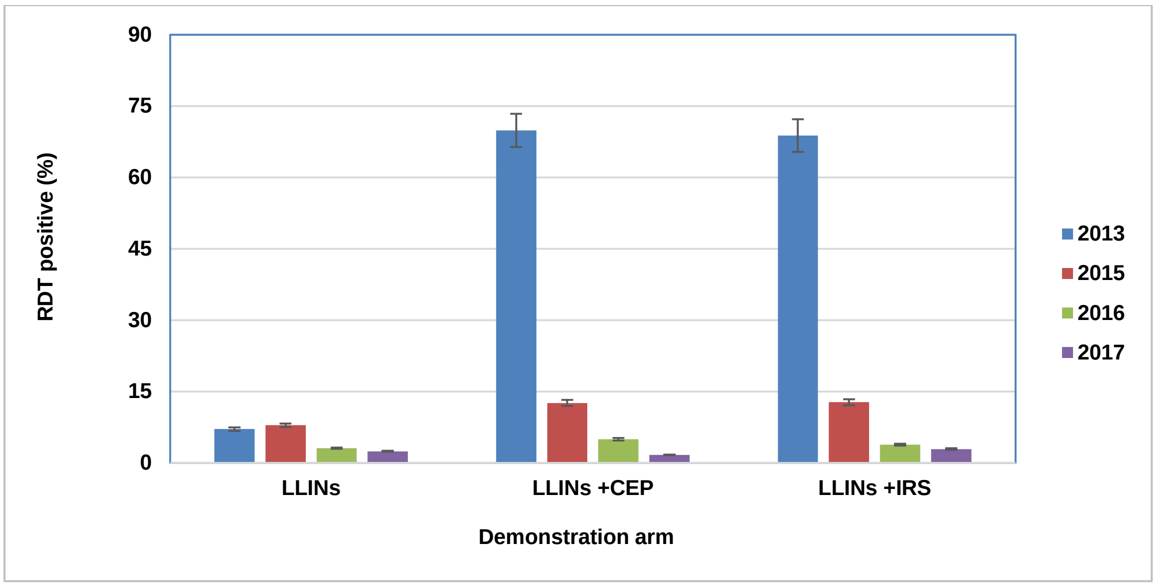
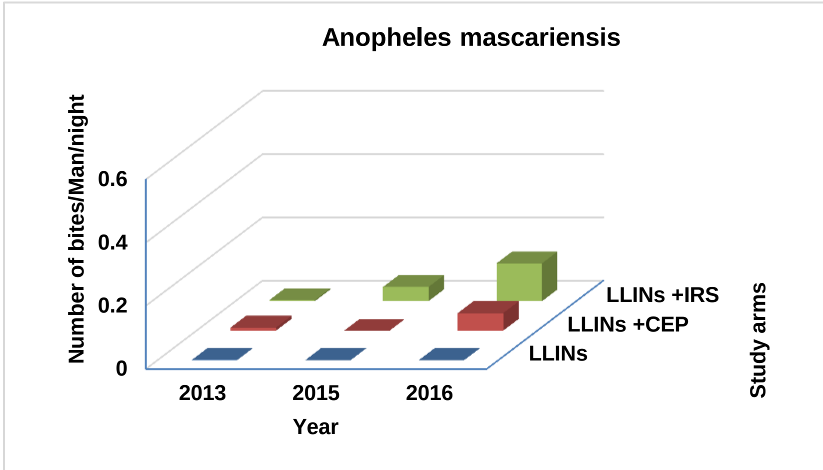
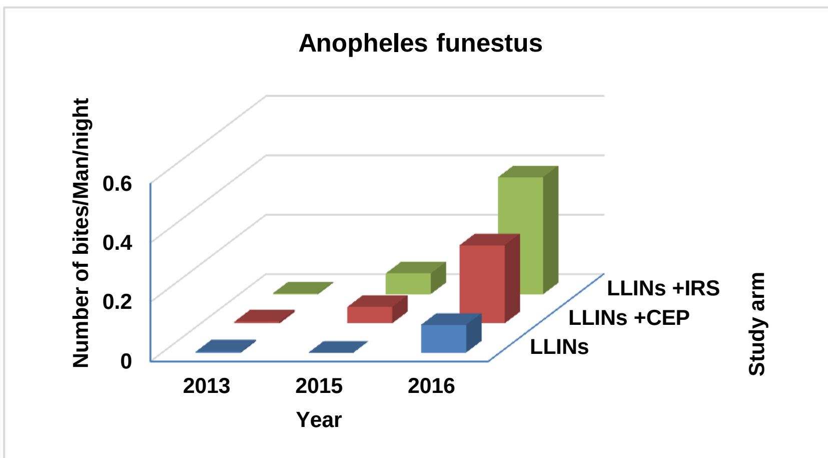


Figure 25: Variations in malaria infection prevalence in Vatomandry District, Madagascar, 2013–2017





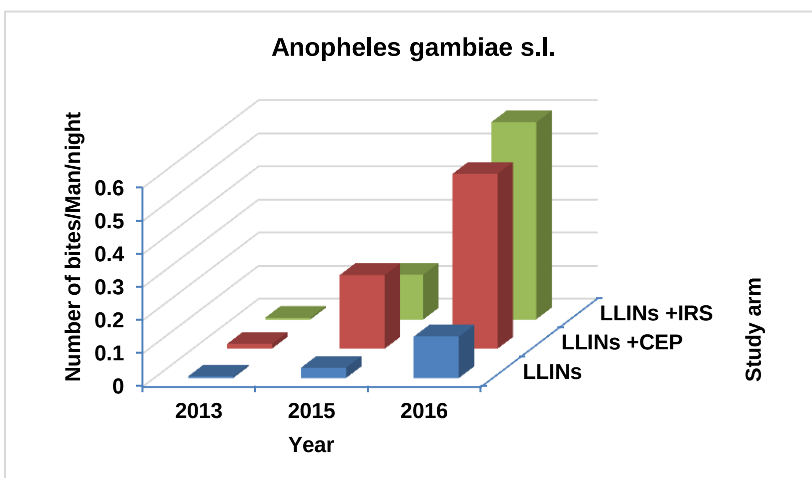


Figure 26: Dynamics of malaria vector populations (bites/person per night by species complex) in Vatomandry District, Madagascar, 2013–2016.

Biting rates in the LLINs + CEP arm were mid-way between the levels recorded in the other two arms. These data suggested that pirimiphos-methyl IRS and CEP strategies had very little impact on malaria vector density and biting rates. Another possibility is changes in vector resting behaviour.

Insecticide resistance testing was carried out in 2016 and 2017, with the three major malaria vector species, using the WHO standard protocol. Most of the tested *An. gambiae s.l.* and all the *An. mascariensis* populations were found to be susceptible to carbamate and organophosphate insecticides, including pirimiphos-methyl (Figure 27). However, resistance to DDT, permethrin, carbamate and organophosphate insecticides was suspected in several *An. funestus* populations. Data on vector susceptibility to pyrethroid insecticides were scarce. *Aedes albopictus*, the vector of zika virus, was also found to be susceptible to bendiocarb and malathion.

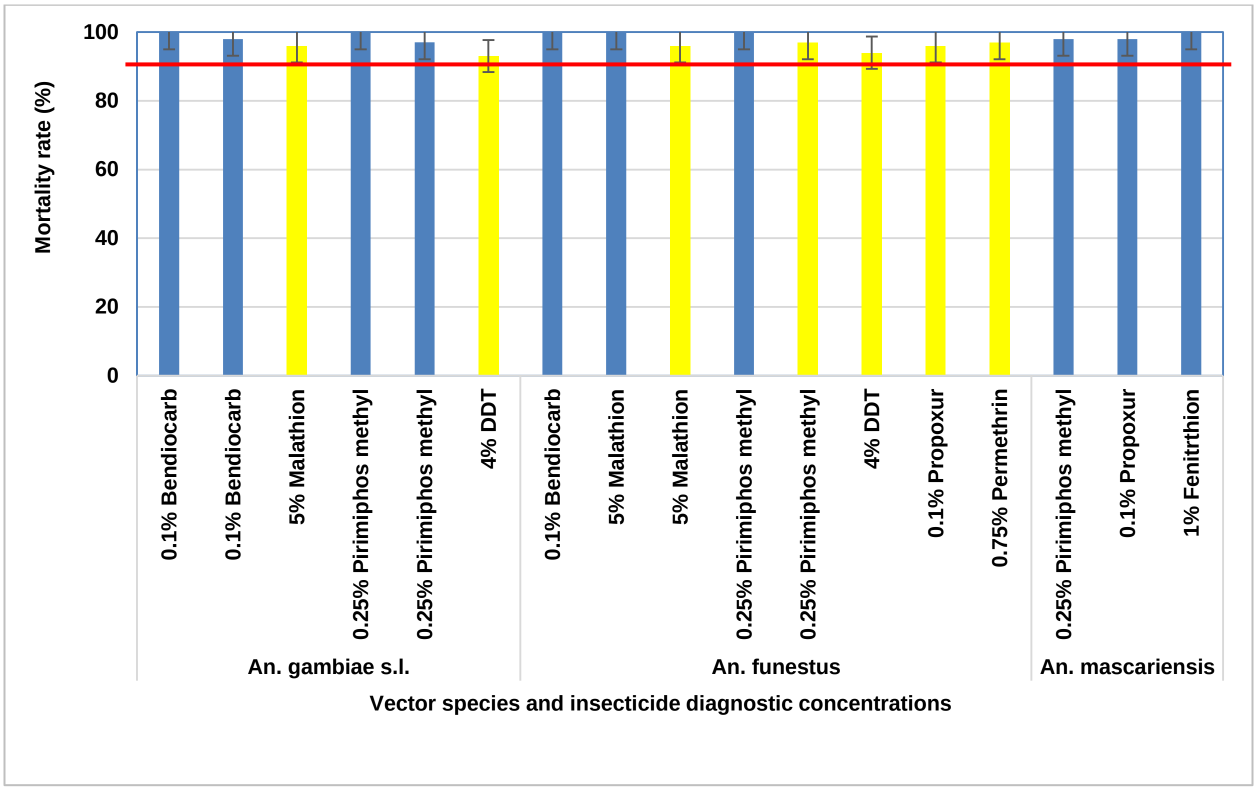


Figure 27: Resistance of *An. gambiae s.l*, *An. funestus* and *An. mascariensis* to insecticides in the Vatomandry demonstration district in Madagascar, 2016-2017

(The red line at 90% mortality indicates the threshold of confirmed resistance in the tested mosquito population. Mortality is based on the WHO standard insecticide susceptibility test procedures)

Expected outcome 2: Locally appropriate alternative malaria vector control interventions implemented

The wide use of LLINs is the core malaria vector control intervention in the three project countries. In addition to ITNs, DDT was routinely used for IRS in Eritrea and Ethiopia before the implementation of this project. The insecticide was considered as an option in the malaria outbreak in Madagascar. However, interruption of DDT use has been maintained in Eritrea since 2012 and in Ethiopia since

2009. In Madagascar, the use of DDT was suspended for more than 10 years, although it continued to be listed as an insecticide for public health purposes. Currently, there is no inclination towards reintroducing DDT, since high DDT resistance in *An. gambiae* s.l., the main malaria vector species in the project countries, is recurrent and widespread. Each country has, therefore, put in place a strategy to promote alternatives.

Eritrea has adopted IVM as the main platform for malaria vector control. This approach includes the deployment of lambda-cyhalothrin or bendiocarb IRS and ITNs, supplemented by larval source management (LSM). There is increased active participation by communities in vector control activities as a result of intensive health promotion campaigns and distribution of necessary materials. Eritrea changed the insecticide policy on IRS in 2012, replacing DDT with lambda-cyhalothrin or bendiocarb. Spraying is done once a year before the onset of the rainy season in selected high malaria-endemic areas and villages. LLINs are routinely distributed free of charge to pregnant women and newborn children. These are supplemented by periodic free mass distributions (every three to four years). By 2015, ≈1.8 million LLINs had been distributed. The LSM package includes larviciding using temephos and biological larvicides (such as *Bacillus thuringiensis var. israelensis* (Bti) and *Bacillus sphaericus* (Bs)) and environmental management through clearing, draining and levelling of potential breeding sites.

In Ethiopia, malaria vector control has been based on IRS since 1959, in combination with LLINs. The IRS policy was changed from DDT to deltamethrin in 2009. However, due to vector resistance to deltamethrin observed in 2012, and since pyrethroid insecticides were reserved for LLINs, spray operations were carried out with propoxur followed by pirimiphos-methyl in four localities selected within the four project districts in August 2015 (Cluster II localities: Bate Germako, Adazer, Guya and Asherie). Control localities (Cluster I localities: Merebie Mermersa, Frishi, Workamaba and Massero) were sprayed with propoxur. Overall, more than 9,521 out of 10,178 (93.5%) structures were sprayed and 24,377 out of 25,471 (95.7%) persons protected by the end of the spray cycle. In addition to IRS, coverage with LLINs in sprayed villages varied from 50% to 90%, and LLIN utilization was >70%.

In Madagascar, three alternative interventions were implemented in the Vatomandry demonstration district: LLINs, LLINs + pirimiphos IRS and LLINs + community engagement and participation (CEP) (Figure 28). Mass distribution of LLINs for personal protection is at the core of the vector control strategy of the National malaria control programme. In 2013, LLIN coverage was >90%; two mass distributions of LLINs were carried out in all the demonstration communes (18,802 LLINs distributed in 2012 and 19,513 LLINs distributed in 2015). However, universal coverage with LLINs was not sustained until February 2015 when coverage reached 52%. Ninety-seven percent (97%) of all LLINs available were used.

In addition to LLINs, two different approaches were introduced: (a) effective CEP supplementing the LLINs in one arm and (b) combined IRS with the LLINs in the other arm. The LLIN intervention alone was taken as the control arm whereas the other two variants – combined LLINs+CEP and combined LLINs+IRS – were taken as interventions under evaluation. Within the four implementation communes, five localities per arm were randomly selected for monitoring (Figure 28). Community leaders and public schools were the key groups involved in the community mobilization effort which took place from January 2016. This IEC/BCC strategy, which was developed based on the outcome of a comprehensive community survey was already adopted in the country health education system and the community mobilization strategy. In order to optimize their role in mobilization activities, a training course on communication techniques and malaria control strategies was organized for school teachers and community leaders. A campaign on sensitization about malaria was conducted every two months in the five clusters selected to host the LLINs + CEP arm. In parallel, daily sensitization was conducted by the community leaders. In the LLINs + IRS arm, pirimiphos-methyl was sprayed in November 2015 and December 2016, with 98%–100% coverage.

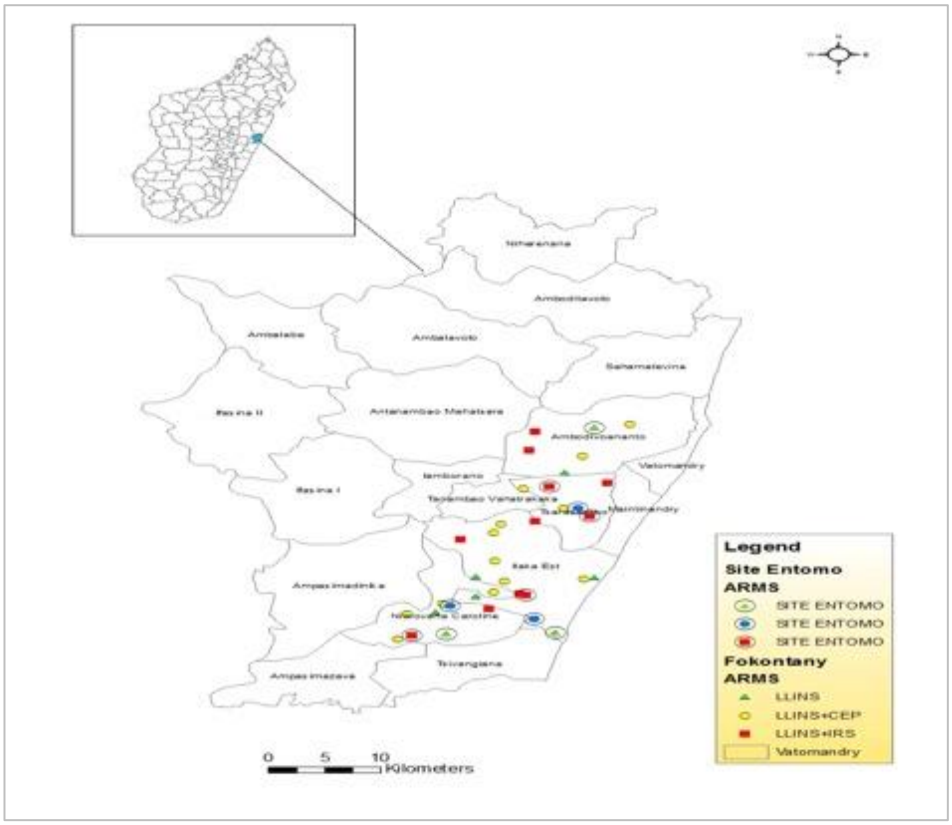


Figure 28: Map of Vatomandry District, Madagascar, showing demonstration arms

Expected outcome 3: Community participation evaluated

Detailed analysis of community attitudes to, knowledge of, and perceptions about, alternative interventions was carried out in Madagascar and Ethiopia. Eritrea already had a long experience in community mobilization and participation in malaria vector control activities.

In Ethiopia, the weaknesses that were identified in IEC/BCC activities resulted in very low participation by the community in malaria prevention and control (Table 4) as it is indicated in outcomes of a survey. The current project, therefore, focused on strengthening community engagement through training, education and mobilization campaigns using different communication materials (audiovisual and print aids) produced by the project. Formulation of a national IEC/BCC strategy was subsequently planned.

In Madagascar, based on the outcome of a community survey, a new IEC/ BCC strategy was designed, implemented, and its impact assessed; the outcomes have been presented in a previous section entitled 'Integrated malaria monitoring and surveillance system developed and implemented'.

Expected outcome 4: Health risk assessment of alternatives conducted

Two countries assessed the environmental and human risk of exposure to pirimiphos-methyl, prepared a statement regarding health risks (including risks to women, children, toddlers and infants) and developed environmental management and monitoring plans.

In Ethiopia, a generic risk assessment model for indoor residual spraying of insecticides (WHO 2011) was applied to assess the impact of pirimiphos-methyl sprayed during the 2015 high malaria transmission season. The assessment targeted pre-spraying, spraying and post-spraying practices, including insecticide storage conditions. The recorded technical specifications of pirimiphos-methyl for IRS operations are provided in Table 5. Overall, irritation and acute toxicity were low. However, the total predicted time-weighted average (TWA) for residents (which is the 'average exposure to a chemical to which the resident may be exposed over a period of 8 hours a day') at systemic doses were not acceptable (23.2 mg/kg bw, 42.4 mg/kg bw and 208 mg/kg bw for adults, children and toddlers respectively). The residential infant exposure through breast milk tolerance systemic dose (TSD) was also not acceptable (1.64 mg/kg bw). Based on the information obtained from the questionnaire, inspection reports, medical records, as well as research reports from the pilot districts, moderate to high risk for human health and environmental impact of pirimiphos-methyl used in IRS was recorded. Furthermore, the capacity of health professionals to diagnose and treat pesticide poisoning was low. The capacity of the health centres in terms of antidotes and other medicines was also weak. For all the human health and environmental risks that were identified during the handling and storage of pirimiphos-methyl for IRS, mitigation measures were proposed (Table 5). A monitoring plan has been developed.

Table 4: Technical specifications of pirimiphos-methyl for IRS operations (Ethiopia)

Description	Measurements
WHO hazard class	U (Unlikely to present acute hazard)
Adverse health effects	Not carcinogenic or genotoxic; not a reprotoxin; not teratogenic
Critical No o**bserved** a**dverse** e**ffect level** '**NOEL**' **(the lowest)**	0.4 mg/kg body weight/day
A**cceptable daily intake (ADI)**	0.01 mg/kg body weight/day
Formulation	Capsulated suspension (CS) 300 g/litre
Dermal exposure during mixing and loading	1 g/m^2
Spray application dosage	40 ml/m^2 (250 g product/10 litres water)
Spray cycle	One operation conducted in one month
Number of exposure days per cycle	24 days
Amount of insecticide in inhaled air	0.4 mg/m^3
Inhaled dose during application	0.003 mg/kg body weight/day
Predicted dose from dermal exposure	0.0004 mg/kg body weight/day
Target dose on the wall	1 g/m^2
Dose after spraying (6 months)	0.8 g/m^2
Predictable systemic dose for resident toddler (14kg)	0.009 mg/kg bw
Residential ingestion dose	Adults: 0.232 mg/kg bw
	Children: 2.08 mg/kg bw
Dermal and oral acute toxicity	Low (i.e., >5000 mg a.i/kg bw for rats)
Total resident predictable time-w**eighted** a**verage (TWA) systemic dose**	Adults: 23.2 mg/kg bw (Not acceptable)
	Children: 42.4 mg/kg bw (Not acceptable)
	Toddlers: 208 mg/kg bw (Not acceptable)
Total infant tolerance systemic dose (TSD) through breast milk	1.64 mg/kg bw (Not acceptable)
Total TWA/TSD	3.14 mg/kg bw

Table 5: Types of risk associated with the use of pirimiphos-methyl for IRS operations and required mitigation measures (Ethiopia)

Types of risk associated with use of pirimiphos-methyl for IRS operations	Measures for mitigating the risks
Driver or community exposure, or environmental contamination due to improper transport of pesticide	⅄ Train drivers, provide appropriate equipment (reliable vehicle, tie-downs, packing materials, tarpaulins, spill clean-up kits)
Environmental contamination due to improper siting or construction of storage and wash facilities	⅄ Use site qualification checklist; locate storage and wash facilities on high ground, above floodplains, away from sensitive receptors (water, birds, bees, fish, children, etc.) ⅄ Use appropriate construction materials as specified in FAO recommendations ⅄ Train storekeepers, team leaders, and supervisors in appropriate storage practices
Cholinesterase inhibition (CI) due to insecticide exposure (resulting in tiredness, dizziness, nausea, blurred vision, headache, sweating, tearing, drooling, vomiting, tunnel vision, twitching, abdominal cramps, muscular tremors or staggering gait)	⅄ Conduct cholinesterase inhibition (CI) testing as needed ⅄ Train team leaders and storekeepers to recognize symptoms and enforce treatment ⅄ Ensure treatment medicines are available in the health centres of the district
Exposure of sprayers or the **community during spray operations due to improper spray procedures and poor personal hygiene**	⅄ Train spray operators, team leaders, supervisors, and health workers to follow best IRS practices ⅄ Discipline sprayers that do not follow proper procedures in all aspects of operations, including personal hygiene
Residential exposure from contaminated household goods	⅄ Train spray operators to refuse to spray houses that are not properly prepared ⅄ Organize IEC campaigns for community education prior to IRS
Spray operator or community exposure due to poor waste management procedures	⅄ Procure barrels for progressive rinses, and wash-tubs for personal hygiene ⅄ Collect, count, and compare the number of empty pesticide bottles to disbursement records; collect worn or torn gloves and masks ⅄ Ship all wastes to authorized incinerators; destroy wastes in front of witnesses
Unacceptable exposure of residents to residue of pirimiphos-methyl on wall surfaces	⅄ Apply best management practices (follow Manual for IRS) ⅄ Collect samples of sprayed surfaces post-IRS to assess resident exposure risk ⅄ Check insecticide residue in samples of floor sweepings
Farm and apiary contamination	⅄ Train farmers and beekeepers in target areas to guard against contamination of agriculture or apiary equipment during IRS operations ⅄ Train pesticide sprayers on the dangers of pesticides to food, fish, birds, and bees
Loss of efficacy of pesticides due to continuous or inappropriate use	⅄ Identify and implement best management practices to avoid public health pesticides being used in agriculture
Vector resistance to the **insecticide used**	⅄ Implement resistance management: resistance testing and monitoring of the use of non-chemical control methods; rotate unrelated insecticides; use mixtures or mosaic treatment

In Madagascar, the level of blood acetylcholinesterase (ACHE) in persons with direct contact with insecticides was assessed as the indicator of contamination. Before and after IRS with the new formulation of pirimiphos-methyl (actellic 300 micro-encapsulated (CS)), the dosage assessment of ACHE was conducted on twenty-five spray agents and twenty-five randomly selected volunteers among people living in pirimiphos-methyl-sprayed houses in 2016 and 2017. The environmental impact assessment was conducted on indoor non-target insects, other disease vectors (*Culex sp*, *Mansoniasp*), and also on the pedofauna. As pits built for insecticide treatments and preparations during the IRS campaigns were the most susceptible spots and the pathway for ground and soil pollution in case of spill of insecticide, and as these pits afforded chances for mishandling materials and non-compliance with technical safety rules, investigations were conducted specifically around these areas.

The average ACHE concentration in human blood was 43.8, 45.0 and 44.2 µg/l for control, residents, and spray operators respectively (Figure 31). No significant difference was observed between control and exposed persons, either in 2016 or in 2017 (p>0.8). Furthermore, no side effects were observed in non-targeted indoor fauna. Species belonging to 18 families of indoor fauna were collected in dwellings sprayed with pirimiphos-methyl (Figure 30), suggesting that the used insecticide did not have a significant impact on the environment.

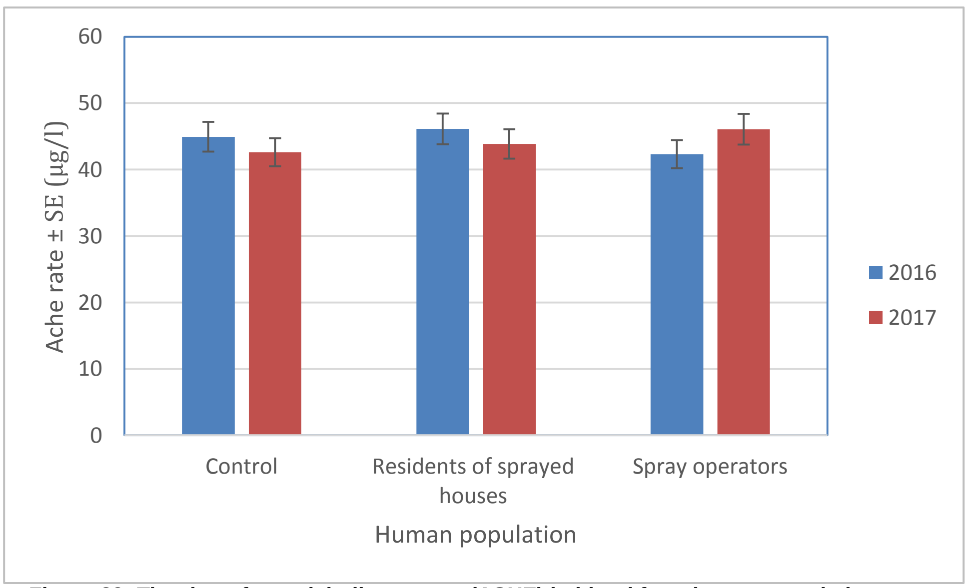


Figure 29: Titration of acetylcholinesterase (ACHE) in blood from human populations post pirimiphos-methyl 300 CS IRS in Vatomandry, Madagascar, 2016-2017

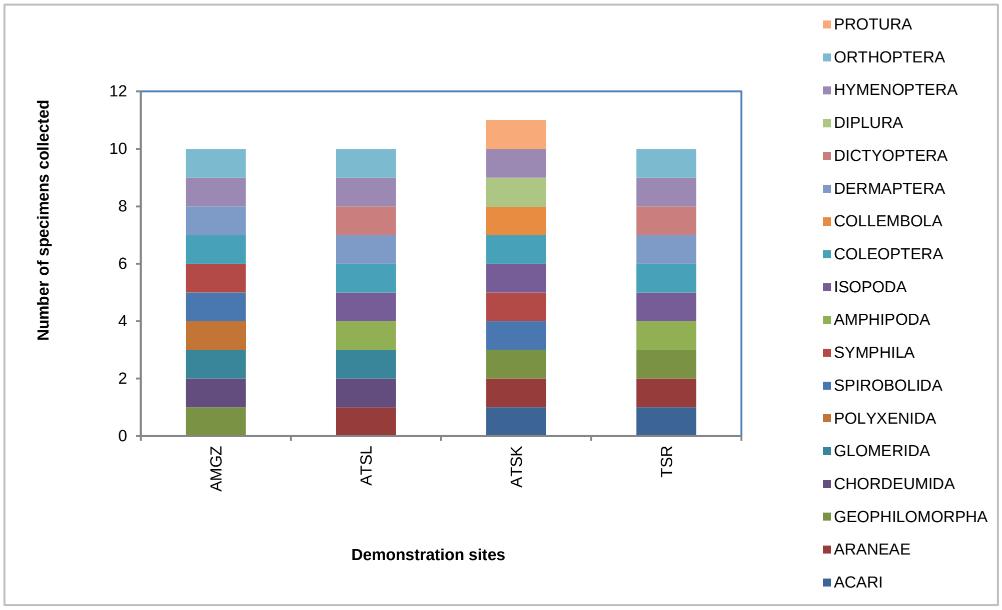


Figure 30: Taxonomic richness of non-targeted insects and pedofauna in houses sprayed with pirimiphos-methyl 300 CS in Vatomandry, Madagascar, 2016-2017

COMPONENT 3: Management and use of DDT and other public health pesticides and disposal of stockpiles

Expected outcome 1: Management of DDT and other pesticides improved

To improve the management of insecticides used in public health, different scenarios were put in place by project teams at country level. They included development of national policy documentation and procedures, and training of spray teams on IRS and management of pesticides. Overall, a total of 458 staff were specifically trained in IRS in the three project countries (Figure 8). The trainees included public health officers, laboratory technicians, insectary attendants, local health assistants, spray supervisors and spray operators. The learners were trained in malaria entomology and key vector control interventions (IRS, LLINs and LSM). The training also stressed practical aspects of IRS including insecticide deposits, under-spraying, over-spraying, handling of spray equipment, safe transport and secure storage, and cleaning and maintenance of spray equipment. Furthermore, a detailed analysis of insecticide management systems was carried out in Eritrea and Ethiopia as described below.

Eritrea: DDT stockpiles, obsolete (38.801 kg) and active (13.321 kg), were reported in 2013, while no DDT has been used since 2012. To improve the management of insecticides, this project strengthened inter-sectoral collaboration by establishing a Vector control technical working group (VCTWG) in charge of resource mobilization, insecticide resistance management, selection of insecticides for vector control, and promotion of safety standards in pesticide use and waste disposal, including operational research [25]. The Ministry for Agriculture regulates the registration, importation and use of pesticides, and ensures the judicious use of pesticides by farmers. The Ministry for Environment promotes effective pesticide management. The project also supported Eritrea to submit a notification that the country will no longer use DDT.

Ethiopia has developed policies and legal instruments for the safe production and use of pesticides. Furthermore, the country has accepted and ratified eight different international conventions and agreements. Institutions dealing with environmental management issues include (a) the Ministry for Environment, Forests and Climate Change; (b) the Federal Ministry of Health; and (c) the Ministry for Agriculture and Natural Resources. However, pesticides, including obsolete DDT (about 928,510 kg in all in the country) were stored near to offices and human dwellings for several years, posing a high risk to human health and the environment. A good portion of these DDT stocks was subsequently shipped to Belgium for disposal by incineration in 2016, but some stocks (some 5,500 kg) remained in place. DDT was purchased and imported from China until the local formulation (at the Adami Tulu Pesticide Formulation Plant), started supplying the chemical. Between 2008 and 2015, the insecticides that were used commonly for malaria control in the country included DDT until 2009. After 2009, deltamethrin, bendiocarb, propoxur, temephos or *Bacillus thuringiensis* (for larviciding) were used. Pirimiphos-methyl 300 g/l SC was procured by WHO in 2015 for use in project districts.

Expected outcome 2: Management of insecticide resistance

With regard to insecticide resistance management, the status of insecticide resistance (IR) in the major malaria vectors of each country has been monitored and well documented. Insecticide resistance management plans (IRMP) have been produced in all the three countries. For instance, in Ethiopia, due to the resistance of malaria vectors to DDT in 2009, and subsequent resistance to deltamethrin in 2012, propoxur and pirimiphos-methyl 300 CS were selected for IRS operations. Country-specific resistance data are presented in a previous section entitled 'Integrated malaria monitoring and surveillance.

A total of 81 staff received specific training on insecticide resistance management (IRM). It had been expected that 95 staff would be trained by the end of project (Figure 8). The trainees included National malaria control programme staff, laboratory and field technicians, and MSc-level students. Nevertheless, trainees who attended both the IVM sessions and the vector control and surveillance sessions were also trained in IRM, increasing the estimated total number of IRM trainees by 35%–40%.

COMPONENT 4: Cross-border information exchanges and technical support to countries achieved

Project outcomes in terms of cross-border information exchanges and technical support to countries were presented in the section on the executing agency's achievements. National IVM committees were set up at the beginning of the project in order to advise the NMCPs and support project implementation and sustainability. All these structures are still operational. In view of the importance of information on the status of insecticide resistance, a regional atlas containing data from 37 countries was produced and shared with all countries. The African network on vector resistance (ANVR) assisted many countries in collecting the data, although some of the information was obtained from partners working on malaria at country level, such as the President's Malaria Initiative (PMI).

COMPONENT 5: Project management

This component relied on five bodies operating through vertical channels (Figure 31) that enabled effective communication to take place as the project was planned, executed, reported upon and resourced. Below are the project management bodies, and their role and responsibilities:

(a) Steering committee: In charge of regular oversight and guidance of the project and provision of technical support to countries for a better implementation of the project plan and for generation of quality data;

(b) Executing agency: The WHO Regional Office for Africa provided technical support, tracked implementation of the plan, managed documentation, prepared reports, etc.;

(c) Implementing agency: UNEP worked closely with AFRO to ensure timely fund disbursements; it assisted with technical and financial reporting; and ensured achievement of project objectives;

(d) Ministries of health in participating countries through their NMCPs: Conducted activities and reported regularly to AFRO;

(e) Partners and local communities: Ensured compliance and assumed ownership of project activities.

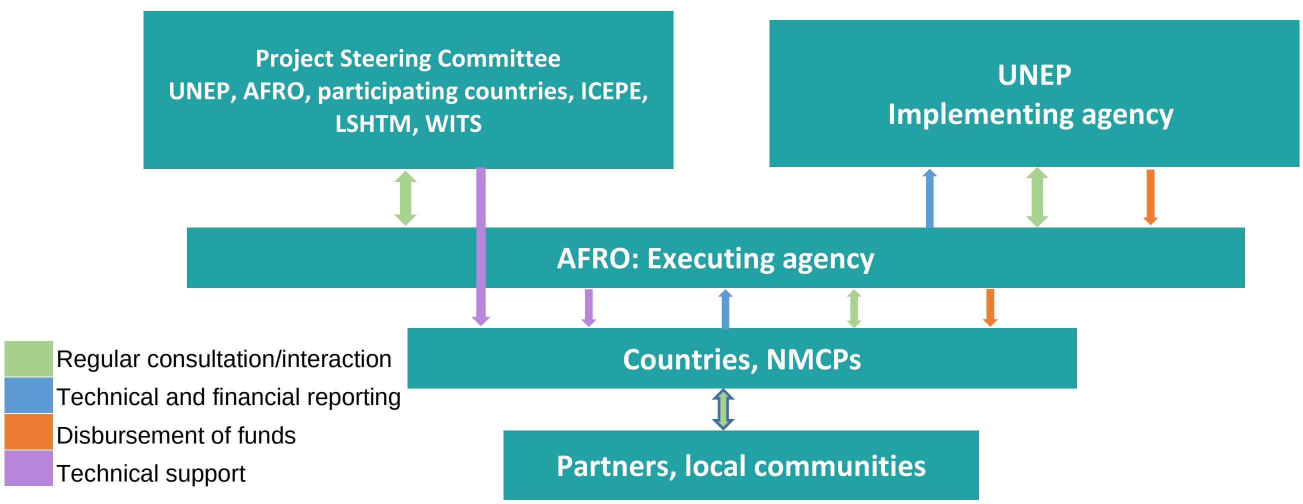


Figure 31: Organization matrix for management of the project

5. Discussion

Various combinations of intervention have been implemented to demonstrate environmentally sound, and locally appropriate alternatives to DDT while strengthening the capacities of implementing countries in different areas of malaria control. Among these alternatives, the wide use of LLINs and malaria case management were the core interventions in the three project countries. IRS with bendiocarb, propoxur or pirimiphos-methyl, CEP, and environmental management were used in addition to LLINs and therapeutic interventions. Although DDT is still listed as an insecticide for public health purposes in the three countries, it might not be reintroduced in malaria control programmes, since community awareness about health risks to humans and the environment has been strengthened. As a result of the alternative interventions and improved capacities for case management and vector control, a noticeable decrease in malaria incidence was recorded in the project districts, regardless of the type of combined intervention.

Lessons from this project include the value of sustaining wide coverage of vector control interventions according to the country's epidemiological situation, and decentralizing the implementation of malaria control activities. These outcomes are consistent with those reported in South Africa where the number of malaria cases and related deaths fell by 89% and 85% respectively, from 64,500 to 6,847 cases and from 460 to 70 deaths, between 2000 and 2012, thanks in large part to effective preventive and therapeutic interventions [18]. However, considering the lifespan of the project, there is a need to develop strategies for the sustainability of control efforts. A sudden resurgence of malaria indicators was already perceived in Ethiopia in 2015 and in Madagascar in 2017. That resurgence was associated with a rapid recolonization of vector populations and with likely changes in their resting and biting behaviour, all of which needs further investigation. Among the factors that may impede the sustainability of alternative strategies are the low residual bio-efficacy of the insecticide used for IRS, the development of vector resistance to insecticides and adaptation of vector populations to insecticide-based interventions [19].

In Eritrea, the residual bio-efficacy of bendiocarb dropped below the threshold of WHO specifications (<80% mortality in exposed mosquitoes) less than three months after spray operations. Similar results were obtained with pirimiphos-methyl IRS on mud walls in Ethiopia, suggesting inconsistency of mud walls (mostly found in project districts) with the pirimiphos-methyl 300 CS formulation. Optimum effectiveness of IRS can be achieved by spraying the right formulation on the right type of surface. However, data on the residual bio-efficacy of propoxur in Ethiopia were not recorded, although the country used this insecticide in some districts, which resulted in a significant decline in malaria indicators. Although the acceptance of pirimiphos-methyl spraying by community members was high, propoxur seems to have been more appropriate for IRS in Ethiopia.

Entomological monitoring revealed that *An. arabiensis* was the main malaria vector in Eritrea and Ethiopia, while the vectorial system was much more complex in Madagascar with three vector species, namely, *An. gambiae s.l., An. funestus* and *An. mascariensis*. It is noteworthy that these species display distinct temporal patterns that fit perfectly with the rainfall sequences, facilitating targeting of IRS operations to high malaria transmission seasons. However, an increase in exophilic tendencies was observed in *An. arabiensis* in response to IRS, and a change in the daily pattern of biting and host choice in response to ITN interventions in Eritrea. Furthermore, susceptibility tests revealed widespread DDT and pyrethroid resistance in *An. gambiae s.l.* and *An.funestus* in the three project countries, as reported in most of the African countries [20]. Currently, pyrethroids are the only insecticides that are recommended for treating bed nets, thanks to their rapid and high knockdown rate, their killing effects on mosquitoes, and their low mammalian toxicity as compared to organochlorine, carbamate and organophosphate compounds. Since LLINs are the core vector control alternatives in most parts of the African Region, there is a need to preserve their effectiveness. Therefore, regular monitoring of vector populations is essential in order to guide the choice of alternative tools and insecticides for resistance management. Furthermore, the search for and promotion of vector control interventions that are not based on the use of insecticides should be strengthened, also taking into consideration their cost-effectiveness.

One of the specific objectives of the project was 'to design, implement, monitor and evaluate studies that will assess the cost-effectiveness and sustainability of alternative interventions'. A cost-effectiveness analysis would provide information on which interventions to adopt for optimal results, and in other cases, give pointers on how to improve the use of existing interventions that previously did not have much impact [21]. With a residual efficacy of less than three months as reported in Eritrea and Ethiopia, countries should plan at least two spray cycles during the high transmission seasons to ensure high coverage of the populations at risk in these countries.

The direct costs of IRS include the procurement and transport of insecticides, training of staff, conduct of spray operations, awareness-raising among communities, safety measures, monitoring of efficacy and insecticide resistance, monitoring of adverse effects on health and the environment, and storage and disposal of obsolete chemicals [9]. All these aspects were tracked during the implementation of the current project; however, their costs were not systematically recorded or computed. In 1990, insecticide costs per house for six months of control were substantially lower for DDT (US$ 1.60) than for other insecticides (>US$ 3.40). But in 1998, the cost range for DDT (US$ 1.50–US$ 3.00) overlapped with that of alternative insecticides (>US$ 2.20), particularly pyrethroids [22]. A comprehensive assessment of cost-effectiveness is, therefore, needed to establish a more solid evidence base for the cost effectiveness of alternatives in relation to DDT.

The current project also demonstrated the important role of the human component in IVM; that role has often been underestimated. People living in high-risk malaria areas must understand the basic causes of this and other vector-borne diseases and how to protect themselves against local vectors. A holistic IVM programme ensures that local communities have the knowledge and support to establish and manage prevention activities. Their involvement is the key to true and effective implementation of alternatives. This aspect has been underscored by WHO as a key element in IVM strategies [11].

6. Lessons learnt

(a) The project generated a significant body of knowledge in malaria entomology, vector control, insecticide resistance monitoring, and policy development. It facilitated the production of strategic and training documentation, resulting not only in increased effectiveness of the programme but also in exerting an inherent positive impact on the disease. In Eritrea, as malaria is eliminated in more areas of the country, implementation of insecticide-based interventions will continue to decline. Accordingly, the risk of reintroducing DDT for malaria vector control will be minimized.

(b) The project helped train health workers to positively diagnose and treat malaria as an evidence-based intervention. Good quality case management can minimize the use of insecticide-based vector control interventions, including the use of DDT.

(c) Monitoring of insecticide resistance under the project has facilitated the development and operationalization of insecticide resistance management plans.

(d) Thanks to the project, entomological surveys carried out suggested an increase in exophilic tendencies in *An. arabiensis* in response to IRS in Eritrea, and a change in host choice and daily patterns of biting in response to ITN interventions. This pointed to the need for more investigations to better characterize local vector populations and identify appropriate interventions and approaches.

(e) The project unveiled the absence of clear guidelines and a favorable environment for the removal and disposal of wastes and obsolete chemicals. It also showed that the apparent lack of support for environmental sanitation in Ethiopia appeared to hamper malaria prevention activities and minimized the impact of prevention efforts at community level.

(f) In Madagascar, the project showed that schools have played an important role in promoting both IEC/BCC activities and use of alternatives to DDT in malaria prevention and control.

(g) The project helped to raise awareness about the precautionary measures that need to be taken during IRS. The measures are very important in mitigating the impact of adverse effects following IRS operations, including the need to seek treatment for minor and major symptoms occurring after such operations.

(h) The project was operational only after the participating countries changed their IRS policies on DDT. That situation played a key role in demonstrating the impact of locally appropriate alternative insecticides such as bendiocarb, propoxur and pirimiphos-methyl for indoor residual spraying.

7. Sustainability

Countries are encouraged to implement the DDT-Alt-Model derived from the project outcomes as shown in the Figure 32 below. This Model relies on two interactive mechanisms, each of which involves six milestones needing to be achieved at the programmatic and operational levels as follows:

(a) Mechanism 1: Effective implementation of IVM. The milestones comprise adaptive strategic planning; available evidence-based alternative tools; a strong integrated malaria control, monitoring and surveillance system; multi-sectoral collaboration and partnerships; an insecticide resistance management plan; sustainable operational research and training plans;

(b) Mechanism 2: Continuous strengthening of local capacities. The milestones include: Knowledge of the usefulness of alternative tools; a locally adapted communication system; well-trained field entomologists; awareness among local communities and their compliance with alternative tools; effective home-based malaria case management; and available national referral centres to support the National malaria control programme.

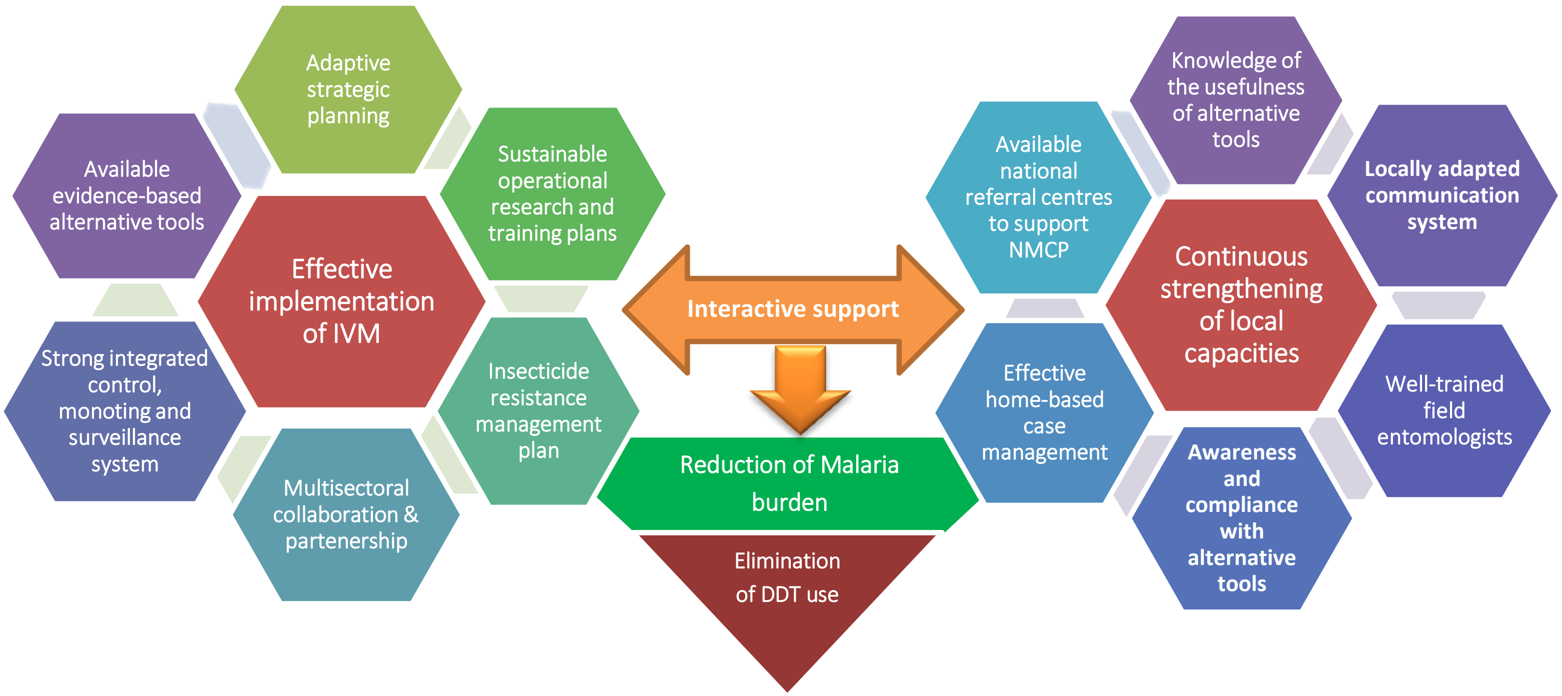


Figure 32: Model for fast-tracking elimination of DDT and implementation of alternatives in malaria control (DDT-Alt-Model)

(a) Achieving at least 80% of these milestones is expected to result in a significant reduction of the malaria burden and, subsequently, in the elimination of DDT use for the purpose of malaria control. A scorecard system can be used to classify country achievements in the implementation of this Model as follows:

  (i) < 8 milestones : Red card

  (ii) 8–10 milestones: Yellow card

  (iii) > 10 milestones: Green card

To implement the DDT-Alt-Model, each country is encouraged to create an 'IVM community workforce' (IVM-CW) in targeted districts to reinforce community engagement. This IVM-CW should involve community leaders, community health workers, spray operators, field entomologists, etc. These constituencies were among the attendees of the training sessions conducted by the country project teams. Since the IVM national committees have been created and are currently functioning as a partnership forum to advise the NMCP, the 'IVM community workforce' should be in charge of the implementation of IVM strategies at the operational level; it is expected that this will also benefit control of other vector-borne diseases. The continuous strengthening of local capacities (knowledge, equipment, commodities and subsidies) will be essential for effective and sustainable implementation of IVM if DDT is to be eliminated from malaria vector control.

(b) This project helped the participating countries to maintain their change of IRS policies regarding the use of DDT in malaria vector control. Subsequent follow-up actions are needed to scale up the experience gained from this project and to prevent participating districts from returning to the use of DDT.

(c) The selected alternatives to DDT should help to minimize or prevent the development of vector resistance to insecticides, which is a major concern in the WHO African Region. When this becomes feasible, countries will no longer depend on DDT to the current extent.

(d) In order to maintain alternative malaria control interventions, district project officers may need to be absorbed into the district administration and charged with the safety, efficacy, affordability and acceptability of alternative tools; those tools should be assessed and implemented.

(e) Furthermore, enhancing the function of national referral centres and bringing them closer to NMCPs and government programmes will require technical assistance for epidemiological surveillance, epidemic forecasting and preparedness, and detection of insecticide resistance.

(f) One of the main bottlenecks in effective prevention of malaria is the amount of funding allocated to malaria by individual governments. There is also the capacity of community members to purchase personal protection items such as ITNs. In Madagascar, the use of ITNs was very low in 2015, leading to an increase in the malaria burden especially among rural and poorer households that are at greater risk. Securing such financing from the government and external bodies (for example, the Global Fund) will substantially improve sustainability of the mechanisms and benefits engendered by this project.

(g) The project participating countries are expected to develop national implementation plans (NIPs) for meeting the requirements of the Stockholm Convention, with specific reference to DDT. Results of demonstration activities should be shared with NIP coordinators. This should give the activities visibility, help strengthen national institutional mechanisms, and enhance continuous funding, thereby contributing to project sustainability.

(h) Sustainability of the transition to alternatives will also depend on fostering ownership at the community and national levels. Therefore, establishing and revitalizing the existing integrated vector management community workforce (IVM-CW) and asking it to take over relevant project activities will guarantee ownership of project activities at community level.

(i) Stakeholder networks developed as a result of this project should be maintained at the national and district levels. They will help ensure sustainability of institutional enforcements as proposed by this project.

8. Replicability

This project showed the applicability of alternatives to DDT and their impact on the malaria burden, with clearly defined replicability at programme level. Experience gained through demonstration interventions was exchanged among the participating countries during Project Steering Committee meetings.

Another group of African countries is now engaged in a similar project (AFRO II). It is expected that DDT-related projects in the African Region will benefit from the experience of the current project countries and that those DDT-related projects will adequately implement alternatives in different areas where application of DDT was intended. It is further expected that replication at the wider inter-regional level will be promoted through meetings of representatives from other regions to demonstrate and exchange ideas on the utility and effectiveness of alternative methods of vector control.

The project has produced the DDT-Alt Model that will be useful not only to other countries in the WHO African Region but also to other regions, particularly in the context of planned GEF projects. WHO will ensure the smooth transfer to others of the knowledge and experience gained from this regional GEF project.

Results deriving from implementation of DDT alternatives in Africa will be disseminated within the network of health-related institutions such as WHO, RBM, and IVM, and to the RBM Vector control working group in order to enhance awareness about the applicability of DDT alternatives and their actual impact on human health and the environment.

9. Recommendations

In order to sustain the actions towards DDT elimination in malaria control, the following key recommendations are made:

To countries

(a) Define locally adapted integrated strategies aimed at reducing insecticide pressure, thus preventing or delaying the development of insecticide resistance; such strategies will also have the effect of reducing dependence on chemical insecticides while lightening the malaria burden and eliminating DDT use, as shown in the DDT-Alt-Model;

(b) Use prequalified carbamates or organophosphate insecticides for IRS, preferably in rotation, in districts where the vectors have developed resistance to DDT or pyrethroids, and monitor their susceptibility to the used insecticides;

(c) Build human resource capacity for vector control, entomology and other IVM activity in order to ensure that programme planning and implementation are tailored to specific needs within each country or local community;

(d) Reinforce the monitoring of entomological and epidemiological malaria indicators in sentinel sites for evidence-based decision-making regarding the choice of appropriate interventions.

To AFRO, UNEP and GEF

(a) Further stimulate country efforts at elimination of DDT in malaria control and promote research on alternative malaria vector control tools;

(b) Continue providing technical support to countries to help them implement the Global plan for insecticide resistance management (GPIRM) and facilitate collaboration between national malaria control programmes and other institutions in matters relating to IVM;

(c) Sustain training, supervision, monitoring and evaluation of malaria control in the WHO African Region;

(d) Support resource mobilization to avoid shortages of entomology equipment and commodities, in order to build strong data collection and analysis systems for evidence-based planning and implementation of vector control interventions.

10. Conclusion

Overall, the project helped to systematically document the impact of changes of insecticide and approaches to malaria vector control. Application of alternative malaria control strategies resulted in a reduction in disease burden in the project districts. Data from Madagascar demonstrated that universal access to LLINs, with very high levels of ownership and utilization (>97%), can be achieved and maintained through continuous distribution and replenishments after mass distribution campaigns, especially when supplemented by effective IEC and BCC. The systematic collation and analysis of retrospective and prospective malaria epidemiological and entomological data resulted in the documentation of disease trends and the resultant clear picture of the malaria burden over the years. The analysis also contributed to fine-tuning of the control strategy to enhance the move towards elimination. Due to its low residual efficacy, pirimiphos-methyl may need to be replaced by another alternative chemical for IRS in Ethiopia. Country capacities have been strengthened to sustain implementation of alternatives to DDT. For better implementation of these strategies, further studies are needed on:

(a) The cost-effectiveness of alternative interventions;

(b) Patterns of vector behaviour in the presence of interventions;

(c) Trends in vector resistance to all the insecticides in use and the mechanisms involved; and

(d) Newly-developed alternatives.

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Annexes

Annex 1 Overview of malaria vector control interventions in project countries with emphasis on DDT utilization in 2009 (start of project) and 2017 (end of project)

Country (District)	Baseline vector control interventions in 2009	End-of-project target	Level in 2017 ('Highly Satisfactory')
Ethiopia (Adama, Sodo, Kola Tembien, Tach Armachio)	• High LLIN coverage • DDT IRS (about 800,000 DDT kg/year)	60% reduction in DDT use	• High LLIN coverage continued • Pirimiphos-methyl IRS in project districts (propoxur in others) • No tendency towards DDT reintroduction • DDT still listed as insecticide for public health
Madagascar (Vatomandry, Atsinanana)	• High LLIN coverage • DDT not used for more than 10 years • DDT listed as possible insecticide to use		• High LLIN coverage continued • Pirimiphos-methyl IRS in project districts (carbamate in others) • No tendency towards DDT reintroduction • DDT still listed as insecticide for public health
Eritrea (Anseba, Debub, Gash-Barka and Northern Red Sea)	• High LLIN coverage • DDT IRS in selected districts (13 002.35 kg) • Targeted larval control		• High LLIN coverage continued • Bendiocarb & lambda cyhalothrin IRS • DDT not used since 2012 • No possibility of DDT reintroduction • DDT still listed as insecticide for public health • Larval control (temephos for larviciding)

Annex 2: Strengthening of national and local capacities for malaria control: outcomes 1 and 2

Outcome	Description of indicator	Baseline in 2009	End-of-project target	Level of achievement in 2017 (Sat–Hi Sat)
1. National and local capacities in planning, monitoring and evaluation of malaria control are strengthened	Number of national and district managers trained in IVM	No information	About 100	23 in Ethiopia 99 in Eritrea 38 in Madagascar
2. Health centres are strengthened for emergency situations	Number of health facilities in project districts with appropriate anti-malarial drugs	No information	Appropriate drugs provided at all health facilities in all project areas	Provision of appropriate drugs to health facilities in all project districts, no stock-out reported
	Number of malaria cases treated promptly at the community level in project areas	Most cases treated promptly at health posts	100% of cases presented to health facilities treated promptly	100% of cases presented to health facilities treated promptly
	Number of health staff trained on proper diagnosis and treatment of malaria	No information	30 health staff/country	96 in Ethiopia 685 in Eritrea 362 in Madagascar
	Number of health facilities with adequate capacities for prompt diagnosis of malaria	No information	9 health facilities	7 health facilities

Annex 4: Strengthening of national and local capacities for malaria control continued: outcomes 3 and 4

Outcome	Description of indicator	Baseline in 2009	End-of-project target	Level of achievement in 2017 (Sat–Hi Sat)
3. Local communities are equipped with insecticides and application apparatus for dealing with emergencies	Availability of contingency stocks of DDT at national level to deal with emergencies	No information	None	NA (all the 3 project countries do not use DDT any longer). But the countries have emergency preparedness stocks of other insecticides
	Availability of a trained team of entomology technicians and sprayers	No trained entomology technicians; but sprayers were available	> 100	• 13 entomologists and 48 sprayers trained in Ethiopia • 17 entomologists and 335 sprayers trained in Eritrea • 5 entomologists and 70 sprayers trained in Madagascar
	Availability of adequate entomological and spray equipment	Minimal	Adequate	Adequate
	Procurement of insecticide and application instruments	No information	No stock-out in study districts	Pirimiphos-methyl procured for Madagascar and Ethiopia
4. National referral centres are strengthened to provide technical assistance	Availability of well-equipped and working national reference centres	0	Expected number not defined	• 2 referral entomology labs (1 in Ethiopia and 1 in Madagascar) • Eritrea built capacity in a partner university

Annex 4: Strengthening of national and local capacities for malaria control continued: outcomes 4, 5 and 6

Outcome	Description of indicator	Baseline in 2009	End-of-project target	Level of achievement in 2017 (Sat–Hi Sat)
4. National referral centres are strengthened to provide technical assistance (contd)	Geo-referenced data on environmental and ecological factors related to vector distribution, distribution of the malaria burden, malaria control interventions, and health system coverage collected, collated and entered	None	Retrospective and prospective geo-referenced epidemiological and entomological data collected from all the project districts	Retroactive and prospective data related to environmental information as well as parasitological and entomological geo-referenced data collected in all the project districts
	Number of health staff working at local level trained to use the Geographic Info. System (GIS) to collect required data	None	50	• 25 staff trained in Eritrea • 9 staff trained in Ethiopia • 8 staff trained in Madagascar
5. Community awareness is raised about alternative interventions; less dependence on DDT	Community involvement in and knowledge about new malaria control approaches and tools (IVM)	None	Communities acquire knowledge about and use alternative interventions	• Madagascar developed an IEC and BCC national strategy based on outcomes and an anthropological survey • Ethiopia conducted an anthropological survey and developed IEC and BCC tools
6. Integrated malaria monitoring and surveillance system developed and implemented	Malaria cases are notified weekly to national malaria control programmes and entered in a MIS database.	None		Cases notified weekly to the district by the health posts in Ethiopia; monthly by health centres to the district in Madagascar but no separate MIS data for project districts

A_5. Implementation of alternative methods of malaria vector control tailored to local circumstances

Outcome	Description of indicator	Baseline in 2009	End-of-project target	Level of achievement in 2017 **(**Sat–Hi Sat)
1. Integrated malaria monitoring and surveillance system is developed	Improved epidemiological data collection, collation and analysis	Scanty epidemiological data, no entomological data	Epidemiological data systematically well managed in all project districts	All 6 project districts have up-to-date parasitological and entomological data, including data on insecticide resistance. Ethiopia has data on anemia as well
	Proper planning, implementation, and evaluation of malaria control, including enhanced vector control	Malaria control planned and implemented but not monitored	Vector control well managed in all project districts	Malaria control monitored and evaluated through data collection and analysis in Ethiopia, Madagascar, and Eritrea
2. Locally appropriate alternative interventions are implemented	Matrix of replicable and transferable results of alternative procedures for malaria control	None	Varied alternative vector control methods implemented in project districts and strategies designed on how to replicate them	• Ethiopia: 1 cycle of pirimiphos-methyl IRS • Eritrea: 1 cycle of bendiocarb & lambda cyhalothrin IRS • Madagascar: 2 cycles IRS • (1st carbamate, and 2nd pirimiphos-methyl
3. Community attitudes to alternative interventions are evaluated	Detailed analysis of the influence of public attitudes on procedures for reduction and prevention of malaria in the Region	Assessment of community attitudes, knowledge and perceptions completed in the three countries	Public attitudes to alternative interventions documented and appropriate actions designed	• Assessment of community attitudes, knowledge and perceptions completed in Ethiopia and Madagascar • New IEC and BCC strategy applied in Madagascar; impact assessed • Strategy has been designed for Ethiopia
4. Environmental and health impact of alternatives is assessed	Assessment of risks to individuals and communities associated with the use of chemical pesticide alternatives	No information	Impact of alternatives on human health and environment documented and disseminated	• Assessment done in Madagascar and Ethiopia • Not planned in Eritrea

Annex 6: Management and use of DDT and other public health pesticides

Outcome	Description of indicator	Baseline level in 2009	End-of-project target	Level of achievement in 2017 — *S-HS*
1. DDT and other pesticides are managed in an environmentally sound manner	1. Documentation of procedures and controls for storage, access, handling and use of DDT and other pesticides where stocks are maintained	Basic procedures on management of DDT and other insecticides existed	Safe custody of DDT and other pesticides maintained in storage for anti-malarial procedures	*Ethiopia:* • Preliminary inventory of obsolete DDT and plan to dispose of the same • Safe pesticide management procedures produced; staff trained in project districts • *Madagascar:* • trained staff in safe pesticide management
	2. Number of spray operators trained in the mixing, handling, safe use, and disposal of DDT	No information	Not defined	• 48 in Ethiopia • 335 in Eritrea • 75 in Madagascar
2. Systems for detecting and managing insecticide resistance are created	Results of susceptibility monitoring activities	Outdated and limited information	Assessment of the susceptibility of malaria vectors to insecticides used for interventions and to detect vector resistance.	• Insecticide resistance (IR) status monitored and well documented; • IR management plans produced in Eritrea, Ethiopia, and Madagascar; • Report on IR situation in the Region produced (Atlas)
	Trained staff in insecticide resistance bioassays	No information	95	• 39 staff in Eritrea • 9 staff in Ethiopia • 33 staff in Madagascar

Annex 7: Mechanisms for project coordination and support structures

Outcome	Description of indicator	Baseline in 2009	End-of-project target	Level of achievement in 2017 **(**Sat–Hi Sat)
Cross-border information exchanges and technical support to countries achieved	Establish project coordination and support structures	None	The established national IVM committee is expected to continue its work as a partnership forum to advise the NMCP in each country	• Coordination structures were established at regional and country levels at the beginning of the project • Established structures were operational as of the end of the project