DDT: last mile in the global phase-out of its use for disease vector control?

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Dichlorodiphenyltrichloroethane (DDT), one of the persistent organic pollutants to be phased out globally under the Stockholm Convention, still continues to be used in some countries as an insecticide for malaria vector control. The global production and use of DDT has reduced substantially over the last 8 years, and the number of alternative insecticides for vector control has increased steadily, suggesting that a global phase-out of DDT is within reach. Only three countries, India, South Africa, and Zimbabwe, were still using DDT in 2023, and a few other countries are keeping the option open of using DDT for emergency response. The main challenges in the global elimination of DDT are that most of the alternative insecticides are less affordable compared with DDT and that the global progress in malaria control and elimination has stagnated. Consultation meetings with countries that intend to use DDT have enabled a sharing of experiences and challenges in phasing out DDT. This Personal View provides recommendations to attain a global phase-out of DDT and to address the problem of disposal of obsolete stocks.

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Introduction

The organochlorine dichlorodiphenyltrichloroethane (DDT) is a controversial chemical. DDT is listed as one of the persistent organic pollutants monitored under the Stockholm Convention on Persistent Organic Pollutants, a global treaty that came into force in 2004 to eliminate the production and use of these substances.[1] Persistent organic pollutants are organic chemicals that remain stable in the environment for long periods, become widely distributed geographically, accumulate in the fatty tissues of humans and animals, including wildlife, and have long-lasting harmful effects on human health and the environment.[2,3] The Stockholm Convention was initiated following concerns about the adverse effects of persistent organic pollutants on human health and the environment. Now, 185 countries plus the EU are parties to the Stockholm Convention.[1] Promisingly, global monitoring of DDT levels measured in air and in human milk or blood samples, or both, showed a declining trend between 2000 and 2019.[4]

Historically, DDT has long been valued as an insecticide in the fight against vector-borne diseases, notably malaria and visceral leishmaniasis.[5] Indoor residual spraying (IRS) is an intervention method by which insecticide is sprayed on walls and ceilings inside residences to kill disease vectors (eg, mosquitoes, sandflies) that rest on these surfaces. DDT has provided disease control programmes with an affordable and effective insecticidal option that has a long residual activity period on sprayed surfaces.

In the negotiations that led to the Stockholm Convention in 2004, the use of DDT was permitted for disease vector control in situations when safe, effective, and affordable alternatives were not available, and in accordance with related recommendations and guidelines issued by WHO.[1] National policy decisions to use DDT for disease vector control are conditional on a detailed analysis that considers all other potential options for vector control and provides clear reasoning for choosing DDT. Hence, WHO considers DDT to be a last resort, not a first choice.[6] In an assessment of health aspects of IRS with DDT, WHO reported that in some geographical areas, human exposures to DDT were higher than levels of potential concern, particularly for unborn children, for infants via lactation, and for spray workers, emphasising the need for best practices to protect residents and spray workers from exposure.[7] Environmental contamination with DDT was associated with IRS operations in some studies.[8–10]

The Stockholm Convention specifies that countries that intend to produce or use DDT should notify the Secretariat, which is hosted by the UN Environment Programme, to be added to the established DDT Register. Countries are required to report every 3 years on their production or use of DDT, or both, through a standard questionnaire.[1]

As DDT was indicated for disease vector control in some countries, a DDT expert group was established in 2005 to meet biennially to review the periodic reports submitted by the countries that are parties to the convention, and other relevant information sources, regarding DDT and its alternatives for disease vector control. Through the Secretariat, the expert group advises the Conference of Parties of the convention about the progress towards the phase-out of DDT and the justification for its continued use for disease vector control.

Over the course of its biennial meetings, the DDT expert group found that a need remains for the use of DDT for disease vector control, but the scope and conditions under which the use of DDT is required have become increasingly focused and country specific. This Personal View outlines some of the findings of DDT expert group meetings conducted since 2005 and assesses the prospects for the global phasing out of this chemical.[11,12]

Trends in the production and use of DDT

Now, DDT is produced only in India, by HIL (India) Limited (formerly Hindustan Insecticides Limited), a Government of India enterprise, at one site in Rasayani, Maharashtra. Until 2018, production also took place at a second site in Udyogmandal, Kerala. In the years before 2008, DDT was produced in both India and China for disease vector control. In 2005, global production was reported to be 6269 metric tonnes (MT) of active ingredient (ai) per year, plateaued at 3000–4000 MT ai per year between 2009 and 2015, and then steadily dropped to a level of 309 MT ai per year in 2023; a drop of 95% from its peak level in 2005 (figure 1).[12] In November, 2024, India indicated that its DDT production for domestic use stopped in mid-2024, but that production continues for export purposes only.

The global use of DDT for disease vector control was the highest in the years after the Stockholm Convention entered into force, with up to 6170 MT ai used per year in 2008. However, after 2008, DDT use dropped to 3441 MT ai in 2009, followed by a gradual decline to 369 MT ai in 2023; a 94% drop from its peak level in 2008 (figure 1).[12,13] DDT has been used mainly for the control of malaria but, until 2016, India also used DDT for the control of the sandfly vectors of visceral leishmaniasis.[12]

Although the decline since 2015 suggests that the use of DDT will soon reach zero, the actual scenario could be different. Specifically, the steep global decline is largely attributable to one country, India, which has long been the world's largest DDT user by far, whereas the use of DDT of late by other countries has been low in comparison, but constant (figure 1). India communicated its plans to discontinue the domestic use of DDT after the usable stocks have been depleted, possibly in 2025.

Besides India, the use of DDT has been largely confined to countries in sub-Saharan Africa since 2004. Ethiopia was once a large-scale user of DDT for malaria control, with a peak of 1445 MT ai of DDT use reported in 2008 (figure 1).[13] However, national health authorities switched to other insecticides and methods for malaria vector control in 2009. Eritrea and Mauritius followed suit. Further, Eswatini and Mozambique last used DDT in 2015, Botswana in 2018, and Namibia and Zambia in 2020.[12] In 2023, DDT was only used in three countries: India, South Africa, and Zimbabwe.[12]

The detection of DDT resistance in vector populations has been a major factor as to why countries shifted from DDT to alternatives for vector control. For example, in Ethiopia, reports of DDT resistance in the main malaria vector *Anopheles arabiensis* caused health authorities to switch to deltamethrin for IRS in 2009.[14] Similarly, high levels of DDT resistance in sandfly vectors caused India to switch from DDT to alpha-cypermethrin for control of visceral leishmaniasis in 2016.[15,16] Malaria vector populations in some countries in southern Africa have remained mostly susceptible to DDT, although of late, signs have indicated that DDT resistance is emerging across the subregion.[17–19]

Stated intention to produce or use DDT

DDT Register

Countries express the intent to produce or use DDT by notifying the DDT Register, but such a notification does not necessarily imply that DDT is being produced or used. Since 2004, 21 countries have been enlisted in the DDT Register. Since then, eight have withdrawn, implying that these countries no longer intend to produce or use DDT, or both (table 1). In addition, The Gambia reported use of DDT in 2009–11 through their questionnaire response but did not notify the DDT Register. Four countries, China, Ethiopia, India, and Namibia, have notified the intent to produce DDT at the same time when they notified the intend to use DDT; China withdrew its notification in 2014.

Intersessional consultation meetings

At its tenth meeting in May, 2021, The Conference of Parties decided to initiate, through the DDT expert group, an intersessional process of consultations with countries in the DDT Register, with the aim of developing DDT phase-out plans and withdrawal from the DDT Register by these countries. The meetings offered to discuss specific situations regarding the current need for DDT and the prospects for the discontinuation of its use in individual countries.[20] The meetings also served to identify supporting interventions for the phase-out of DDT, and provided insight into the specific challenges and needs of countries in phasing out the use of DDT (panel 1). Since the meetings started in 2022, five countries, namely, Madagascar, Marshall Islands, Mozambique, Venezuela, and Yemen, have withdrawn from the DDT Register.

The countries that remain in the DDT Register include some (Federated States of Micronesia and Senegal) that have no history of DDT use of late and are, thus, most unlikely to revert to DDT. Of the countries that used DDT of late, Eswatini, Mauritius, and Uganda reported that they keep the option open of using DDT for emergency purposes for disease vector control. Ethiopia banned the use of DDT in 2010 but remains enlisted in the DDT Register. Mozambique last used DDT for malaria vector control in 2015 and withdrew from the DDT Register in 2023. The intent to use DDT by Botswana and Eritrea remains unknown. Namibia and Zambia stated no plans to reintroduce the use of DDT in the future, but their withdrawal from the DDT Register is pending. India reported plans to phase out the use of DDT in 2025. South Africa still uses DDT but has plans to shift to alternatives as soon as possible, depending on their availability and affordability. Zimbabwe intends to make DDT the last option for use in IRS, taking affordability into consideration. Several countries in southern Africa, including Namibia, South Africa, Zimbabwe, and Zambia, requested support for registration, local evaluation, and uptake of newly developed IRS products as alternatives to DDT through subregional collaboration.

Alternative products and intervention methods

For an insecticide to be considered for public health use, the compound needs to be lethal to vector insects upon contact, and safe to humans, among other criteria. Insecticides are grouped into classes that share a common mode of action in insects that come in contact with them.[21]

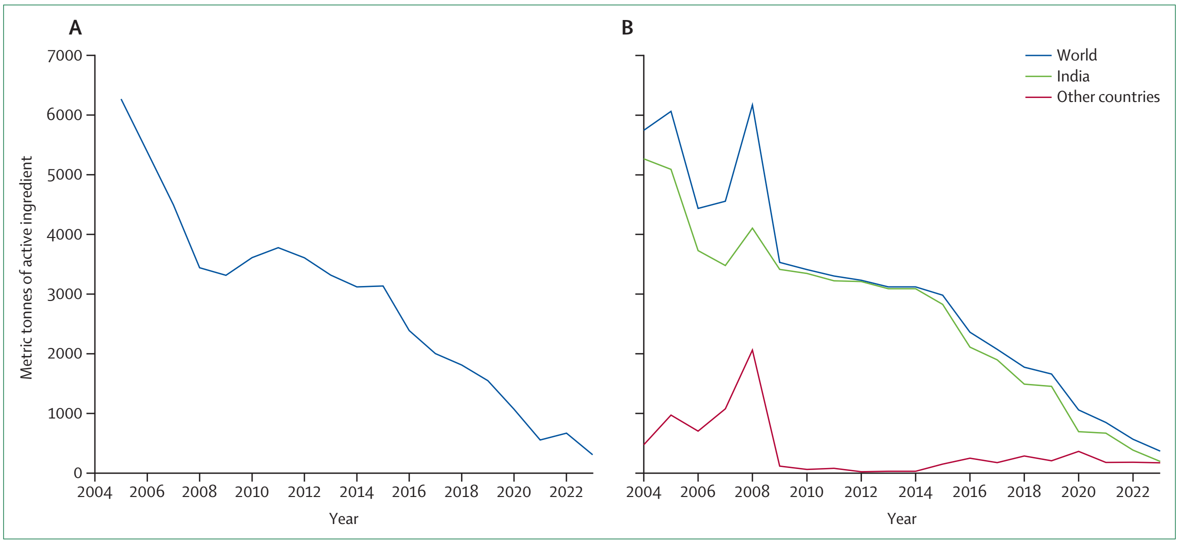

Figure 1: **Global annual trends in DDT production and use for disease vector control since the year the Stockholm Convention entered into force—2004**
(A) Production. (B) Use. Data on production of DDT were obtained from the DDT expert group reports; annual data were missing for 2004 and 2006.[12] Data on DDT use were obtained from DDT expert group reports for the years 2009–23;[12] due to a paucity of data for 2004–08, independently collected data by WHO were used for this period.[13] DDT=dichlorodiphenyltrichloroethane.

A major challenge in disease vector control is the development of insecticide resistance in vector populations, which can compromise the effectiveness of the insecticides used.[22] The development of insecticide resistance in vectors usually gives cross-resistance to the entire class of an insecticide. Since the 1990s, pyrethroid insecticides became widely used for IRS and ITNs, which led to widespread resistance to pyrethroids in malaria vectors, particularly in sub-Saharan Africa.[19] The problem of a small arsenal of vector control insecticides to respond to insecticide resistance was highlighted in 2002 in a call for the development of additional insecticides.[23] Since then, efforts and investments by the international community have led to the development of new alternatives to DDT for disease vector control. With regard to DDT alternatives, this Personal View focuses on the ones used to control malaria, which is the only disease for which DDT continues to be used.

For large-scale deployment, WHO recommends two malaria vector control interventions, IRS and ITNs, due to their proven public health value; and conditionally recommends larviciding of aquatic vector breeding sites and house screening (installation of screening of windows, doors, etc, to block mosquito entry) as supplementary interventions.[6] The number of alternative vector control products, insecticide active ingredients, and insecticide classes that have received WHO prequalification have increased substantially for IRS, ITNs, and larviciding, but no products for house screening have been evaluated of date (figure 2; see panel 2 for definitions).

Before 2017, only two insecticide classes, namely carbamates and pyrethroids, received WHO prequalification for use in IRS, but since 2017, insecticides in new classes have been prequalified, thereby widening the options to confront insecticide resistance development. These classes include organophosphates (pirimiphosmethyl as active ingredient), neonicotinoids (clothianidin as active ingredient), metadiamides (broflanilide as active ingredient), and pyrroles (chlorfenapyr as active ingredient) (figure 2). The number of active ingredients that received WHO prequalification

	DDT Register: Year of notification (and withdrawal)	Year of last reported use of DDT
Botswana	2004	2018
China	2005 (2014)	Before 2004
Eritrea	2010	2012
Eswatini	2006	2015
Ethiopia	2006	2009
Federated States of Micronesia	2020	Before 2004
India	2006	2023 (and ongoing)
Madagascar	2007 (2023)	2004
Marshall Islands	2004 (2023)	Before 2004
Mauritius	2007	2010
Morocco	2005 (2015)	Before 2004
Mozambique	2007 (2024)	2015
Myanmar	2006 (2012)	2006
Namibia	2009	2020
Senegal	2006	Before 2004
South Africa	2004	2023 (and ongoing)
Uganda	2008	2008
Venezuela	2009 (2024)	Before 2004
Yemen	2005 (2023)	Before 2004
Zambia	2008	2020
Zimbabwe	2018	2023 (and ongoing)

Table 1: **Countries in the DDT Register, indicating year of last use of DDT for disease vector control**

Panel 1: Country-specific situation regarding dichlorodiphenyltrichloroethane (DDT)

A short description is given for each country (as parties to the Stockholm Convention) enlisted in the DDT Register, of their situation regarding the use or intended use of DDT for disease vector control. The information was obtained through intersessional consultation meetings with participation by country representatives, supplemented with DDT questionnaire responses, as documented in the DDT expert group reports.

Countries using DDT in 2018–23 and planning or exploring to phase out

India

This country has long been the largest user and only producer of DDT but plans to phase out its use in 2025. Factors that contributed to the declining use of DDT in India included national policy support for the phase-out of DDT, DDT resistance in populations of vectors of visceral leishmaniasis and malaria, an increased use of pyrethroid-insecticide-treated nets (ITNs), a shift from the use of DDT to alternative insecticides for indoor residual spraying (IRS), use of larvicides for urban malaria control, and latest progress in the control of malaria in the country. The development, evaluation, registration, and uptake of alternatives to DDT remain a priority for the country. With support from the Global Environment Facility, the public sector manufacturing enterprise HIL (India) Limited largely shifted from the production of DDT towards the development, production, and upscaling of alternatives, notably ITNs and *Bacillus thuringiensis* subspecies *israelensis*, in 2024. As HIL (India) Limited continues to export DDT to a few African countries, such as South Africa and Zimbabwe, India needs clear guidance about until when the country needs to keep DDT production facilities open for export purpose. Hence, transparency and communication through the intersessional consultation meetings will be crucial.

Namibia

Namibia has been a long-time user of DDT for malaria vector control. Until 2020, Namibia used DDT and several alternative insecticides for IRS in the northern regions. The emergence of DDT resistance from 2020 caused IRS operations to progressively rely on alternative insecticides in the context of insecticide resistance management. Namibia has indicated not using DDT since 2021 and initiating a process of policy change for phasing out DDT.

South Africa

DDT continues to be used in the three malaria-endemic provinces of South Africa, where the chemical is sprayed on mud or unplastered structures. Malaria vector control operations use IRS during the transmission season and, wherever appropriate, larval source management, which includes winter larviciding. Several pilot studies have been undertaken with the latest insecticide products for IRS and have shown promising results. The plan is to continue to use a mosaic IRS approach to manage insecticide resistance, with a possible shift to annual insecticide rotations in the coming years. South Africa is committed to phasing out DDT as soon as possible. In the short term, however, South Africa has indicated that the country still needs DDT for malaria vector control because of the high cost and complexities of procurement of effective alternative insecticides, compared with DDT. Interministerial coordination and further political support will be needed to make a full switch to alternatives.

Zambia

Zambia has adopted both IRS and ITNs for malaria vector control. DDT and alternative insecticide products have been used in rotation for IRS, to manage insecticide resistance in this country. Zambia is committed to phasing out DDT in the control and elimination of malaria. Reported challenges are the inadequate monitoring of aspects of DDT use, insufficient skills and research on alternatives to DDT, and poor coordination between stakeholders. In its latest questionnaire response, Zambia stated that the country has phased out the use of DDT for malaria vector control in 2021 and rotated to other non-persistent organic pollutant insecticides. A policy change is pending.

Countries using DDT in 2018–23 but not planning to phase out

Botswana

Botswana last reported the use of DDT for malaria vector control in 2018 but reportedly made the switch from DDT to alternative insecticides in IRS. However, a formal policy decision regarding DDT is pending.

Zimbabwe

Zimbabwe remains the largest user of DDT for malaria control among African countries, reporting an average use of 158 metric tonnes (MT) active ingredient of DDT per year in 2018–23. DDT is used in rotation with other insecticides in IRS operations. Challenges in the phase-out of DDT in Zimbabwe include the high cost of alternative insecticides and the prospect of resistance against alternative insecticide products. Zimbabwe intends to make DDT the last option for use in IRS, after all other options (and their costs) have been considered.

Countries not using DDT in 2018–23 and preparing to withdraw from the DDT Register

Ethiopia

Ethiopia stopped using DDT for malaria control in 2010. Large stockpiles of obsolete DDT are being safeguarded for disposal with external funding support. The country is planning to withdraw from the DDT Register.

Mauritius

No DDT has been used in Mauritius since 2011. Malaria has been eliminated in the country and, to prevent the re-establishment of malaria, Mauritius has retained 5 MT of DDT product for emergency purposes. However, the potency of the ageing stocks has been questioned. Mauritius is considering phasing out DDT and withdrawing from the DDT Register.

Senegal

DDT was last used for malaria vector control in Senegal before 2004, and the country reported no usable or obsolete stocks of DDT. Newly developed insecticide products are being used for IRS. A decision on a withdrawal from the DDT Register is pending.

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Panel 1 continued from previous page

Countries not using DDT in 2018–23 and not planning to withdraw from the DDT Register

Eswatini

DDT was last used for malaria vector control in Eswatini in 2015, and reportedly, the chemical is unlikely to be used in the foreseeable future. Alternative IRS insecticides have been adopted for use in IRS. However, DDT is kept for emergency purposes for vector-borne disease outbreaks and Eswatini has no intention to withdraw from the DDT Register. The disposal of obsolete DDT stocks presents a major challenge to the country.

Uganda

Uganda uses ITNs and IRS for malaria vector control. DDT has not been used in Uganda since 2008. In 2008, Uganda briefly reintroduced DDT for malaria vector control in two districts for one transmission season, but the use of DDT was stopped by a High Court order; the injunction was later lifted, but DDT use was not resumed thereafter. Uganda has no available stocks of DDT. However, the country keeps the option open of using DDT as last resort and, hence, intends to remain in the DDT Register.

The two remaining countries in the DDT Register, Eritrea and Federated States of Micronesia, did not participate in the consultation meetings and, consequently, their plans regarding the DDT Register remain unknown. Eritrea last reported the use of DDT in 2012 and Federated States of Micronesia reported the same before 2004.

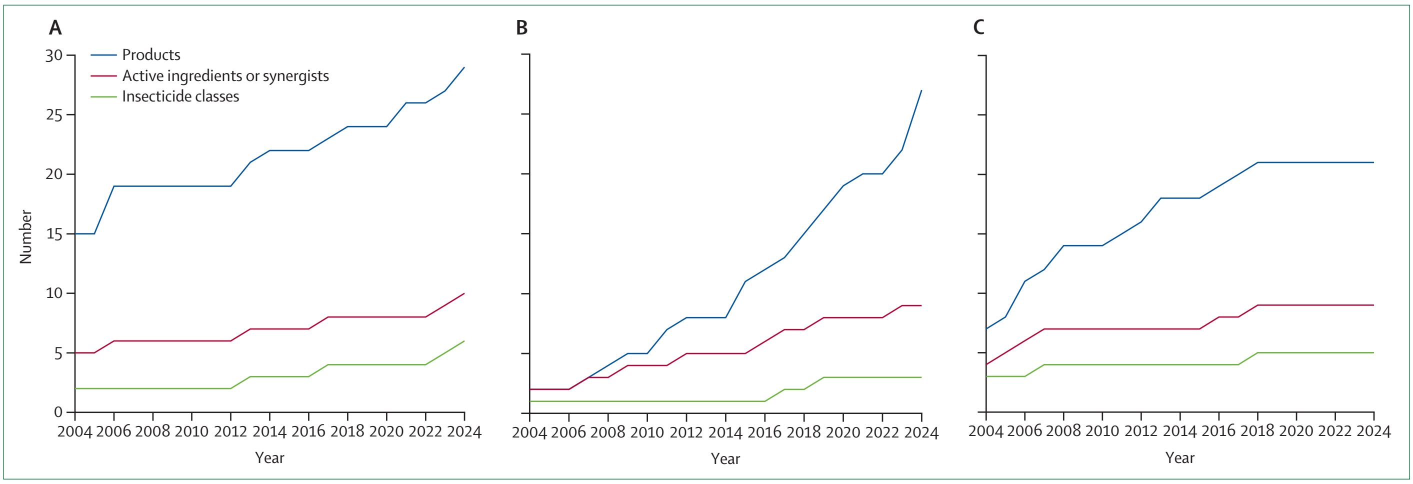

Figure 2: **Number of products, active ingredients, and insecticide classes available for vector control, by year**

A) Indoor residual spraying. B) Insecticide-treated nets. C) Larviciding. Presented are products that received WHO prequalification (data adapted from[24]). In 2017, the former WHO Pesticide Evaluation Scheme was transitioned to a prequalification system to assess vector control products for their safety, effectiveness, and manufacturing quality. Most products that had been recommended by the WHO Pesticide Evaluation Scheme until 2017 were prequalified according to the new system.[25] However, a few vector control insecticides (including the organophosphates malathion and fenitrothion, and the organochlorine dichlorodiphenyltrichloroethane) could not be converted to the new system for reasons such as human safety, retractions, or non-submission of dossiers by the respective manufacturers, and are excluded from the figure.

for IRS increased, from five in 2004 to ten in 2024, whereas the number of IRS products that received WHO prequalification rose from 15 in 2004 to 29 in 2024. The latest IRS products generally have a long-lasting period of residual activity after being sprayed on surfaces, thereby reducing the number of spray rounds needed in settings with lengthy malaria transmission seasons.

The surge in the number of marketed products is expected to increase competition and drive prices down. At current market prices, however, alternative IRS products other than pyrethroids remain costlier than DDT. A 2022 analysis of IRS operations of the US President's Malaria Initiative in 13 African countries showed that the average cost of IRS was US$7·69 per person protected per year, and the cost of procuring the latest insecticides made up 25·5% of the total costs of IRS operations.[26] These procurement costs were approximately 2·2–4·3 times higher than those for DDT and 4·8–8·7 times higher than those for pyrethroids at current market prices.[27] Based on these data, using the latest insecticides for IRS would cost 15·9–24·4% more per person protected, as compared with using DDT. A comprehensive cost–benefit analysis of DDT versus alternative IRS insecticides that includes indirect costs is lacking. The use and coverage of IRS for malaria vector control has declined markedly since 2010, largely due to escalating costs and stagnating resources.[28–30] Globally, the percentage of the population at risk, protected by IRS, dropped from 5·3% in 2010 to 1·6% in 2023.[28]

ITNs are a widely used alternative tool to IRS for malaria vector control (figure 2). For many years, manually treated and factory-made ITNs used only pyrethroid insecticides as active ingredients, which contributed to the development of pyrethroid resistance in vector populations. The use of synergists can partly or fully restore susceptibility to

Panel 2: Definitions

Active ingredient
An active ingredient is the chemical in the insecticide product that acts to kill, control, or repel insects.

Insecticide class
An insecticide class is a group of insecticides that share a common chemical structure (eg, pyrethroids, organochlorines).

Mode of action
The mode of action is the manner in which an insecticide interferes with the biochemistry or behaviour of insects. Most insecticide classes have a unique mode of action, but some classes share the same mode of action (eg, carbamates and organophosphates are both acetylcholinesterase inhibitors).

Synergist
A synergist is a chemical added to an insecticide to render the insecticide more effective at killing insects.

Vector control product
A vector control product is any marketable tool designed to reduce infection or disease caused by a vector-borne pathogen, or both, through control of the disease vector.

pyrethroids in resistant mosquitoes. One such synergist is piperonyl butoxide, which has been added to some pyrethroid net products since 2009 (figure 2). These nets have shown high effectiveness against pyrethroid-resistant mosquitoes.[31] From 2017, dual-insecticide ITNs became available, most notably a net combining a pyrethroid and chlorfenapyr, which belongs to the class of pyrrole insecticides. These nets have shown high effectiveness against pyrethroid-resistant mosquitoes.[32] Additionally, ITNs with a pyrethroid and the insect growth regulator pyriproxyfen have also been developed, but their superiority over pyrethroid-only nets has been inconclusive.[32]

The number of active ingredient and synergist combinations of ITNs increased from two in 2004 to nine in 2024, and the number of ITN products that received WHO prequalification also rose steeply from two in 2004 to 27 to 2024, implying that the options for ITN products have increased markedly. At current prices, the cost per person protected can be substantially lower for ITNs than for IRS, depending on the country context.[27] The contribution of pyrethroid-piperonyl butoxide ITNs and dual-insecticide ITNs to the total ITNs delivered worldwide has increased rapidly since they became available; by 2024, 30% of ITNs delivered were pyrethroid-piperonyl butoxide ITNs and 47% were dual-insecticide ITNs.[33]

The disposal of worn-out nets that are no longer used is of increasing concern. Schemes for collection of worn-out nets and bailing material for environmentally sound disposal are still largely unavailable. The options and feasibility for their environmentally sound and safe disposal require urgent solutions. WHO recommends disposal through high-temperature incineration or, in the absence of appropriate facilities, by burying away from water sources and preferably in non-permeable soil.[6] We suggest that a scoping assessment is initiated for the safe disposal of wastes resulting from worn-out nets and bailing material.

Larvicides that have received WHO prequalification include products in several insecticide classes (figure 2), and some of these classes (eg, bacterial larvicides) are unique to this intervention method. The number of prequalified larvicide active ingredients and products increased until 2018, but no new products were prequalified thereafter. Ideally, larviciding is part of larval source management, whereby larvicide applications complement the environmental management of aquatic breeding sites, wherever possible.[34]

Sustainability strategies

Integrated vector management (IVM) has been advocated as a broad-based approach to improve the efficiency, effectiveness, and sustainability of disease vector control, through the combination of vector control methods, and with the engagement of other public or private sectors and communities.[35] This approach has the potential to reduce the reliance on DDT and other chemical insecticides for disease vector control. For example, wherever appropriate, IVM could use targeted IRS with or without co-deployment of ITNs. Wherever feasible, these interventions could be combined with larval source management, house improvements, and active involvement of local communities and authorities outside the health sector, such as irrigation, agriculture, and municipalities.[36–38] Preserving the effectiveness of insecticides for as long as possible using an integrated approach is crucial wherever insecticides are used for malaria vector control. However, the insecticidal action of interventions such as IRS and ITNs exerts a continuous selection pressure in vector populations, which can eventually lead to resistance.

Insecticide resistance management is a strategy to prevent or delay resistance through rotational use (ie, the periodic switching between insecticide classes over time), mosaic application (ie, the use of different insecticide classes between houses or geographical areas), use of mixtures (ie, the use of two or more insecticide classes in a single formulation) or sequences (ie, the continuous deployment of an insecticide until a level of resistance is reached, after which a switch is made to another insecticide class) of insecticides with different modes of action and wherever cross-resistance between insecticide classes is absent. However, there is insufficient evidence regarding the effectiveness and feasibility of different insecticide resistance management strategies.[39,40] Rotations might be practical for IRS and larviciding programmes that can annually replace the insecticide with an unrelated mode of action, but not for ITNs, which are generally replaced after 3 years of use.

WHO-prequalified IRS products include five insecticide classes that present several distinct modes of action for use in insecticide resistance management, on the assumption of susceptibility in vector populations. Between 2018 and 2023, resistance in malaria vectors to at least one insecticide class was reported from 86% of the 66 countries in which tests were carried out.[28] The occurrence of insecticide resistance varies between regions, being most common in the African and South-East Asia regions of WHO.[19] Consequently, insecticide resistance management should be supported by regular monitoring of insecticide susceptibility in representative sites, using standard susceptibility bioassays.[41] Some countries in southern Africa, such as South Africa and Zimbabwe, use DDT as a component of an insecticide resistance management strategy, but this approach is not suited wherever vector populations show cross-resistance between DDT and pyrethroids.

Efforts to enable a shift to alternatives

Policy development and capacity building

At international level, policy and normative support exist for IVM and insecticide resistance management.[35,36,40,42] Developments in implementation of key areas of IVM have been documented for some countries, serving as examples of this approach.[43–45] In 2018, IVM policy was reported to be in place in 48 of the 93 targeted countries.[46] However, the implementation of IVM has been slow due to factors such as inadequate entomological capacity and capability in countries, and challenges in restructuring of existing vector control programmes.[47] To enhance the implementation of IVM, WHO launched the Global Vector Control Response 2017–30, which calls on countries and development partners to strengthen vector control as a fundamental approach to preventing vector-borne disease and responding to outbreaks.[48] In 2021, a global survey that assessed national implementation of priority activities of the Global Vector Control Response reported that targets were not reached for most activities, pointing out that allocated funds have been far less than the costed plan.[49]

In regions at risk of malaria, 81% of countries reportedly have a plan for the monitoring of insecticide resistance.[50] However, the available evidence suggests that the implementation of insecticide resistance management has generally been poor, with the exception of several African countries.[51–53]

Capacity building is central to the transitioning towards alternatives to DDT for malaria vector control. Capacity for vector surveillance and control is needed for the selection of appropriate products or methods, for optimal timing and targeting of control interventions, and for the evaluation of the effectiveness of vector control interventions. Despite considerable investment, a general shortage of public health entomological capacity exists in countries at risk of vector-borne diseases, partly due to inadequate career opportunities for entomologists within the public health and medical sectors, along with a shortage of laboratory capacity for processing of samples and for conducting insecticide resistance testing.[54–57]

The Global Environment Facility has supported countries in capacity building for using alternatives to DDT, including support for the public sector manufacturing enterprise HIL (India) Limited to shift from the production of DDT towards the production of alternatives (panel 1), and support for testing and implementation of IVM approaches in African countries.[58] This support has played a pivotal role in phasing out DDT.

	Mode of action	Status
Attractive targeted sugar baits	Toxic bait stations to kill sugar-feeding mosquitoes	Trials in Mali, Kenya, and Zambia completed
Eave tubes	Insecticide in eave tube kills mosquitoes upon house entry	Trials in Cote d'Ivoire and Uganda ongoing
Endectocides	Ivermectin to kill mosquitoes through blood meal	Trials in Mozambique and Kenya being completed
Spatial repellents	Mosquito repellence by airborne chemicals	Trial in Kenya completed, and trial in Mali being completed
Topical repellents	Mosquito repellence by application to skin	Trials being planned
Gene drive technology	Genetic modification to reduce vector fecundity or change the sex ratio	Laboratory testing ongoing

Table 2: **New intervention methods for malaria vector control under evaluation by WHO.**

Innovation and evaluation

The innovation, development, and evaluation of new products for vector control continues to be a productive effort involving academic and industry partners.[59] In addition to IRS and ITNs, novel vector control methods are needed in many settings to control or eliminate malaria,[60,61] because IRS and ITNs, although locally effective, can only provide partial protection against mosquito bites due to the time that people are exposed while staying outdoors or indoors not under an ITN. Substantial innovation and evaluation have taken place beyond the conventional intervention methods, including non-chemical approaches, but none of these have so far reached the stage of showing enough public health impact to receive a recommendation by the WHO's vector control advisory group to prequalify them for operational deployment.[62] Intervention methods at various stages of review by the vector control advisory group for malaria vector control include bait stations, eave tubes, systemic endectocide treatment, spatial repellents, topical repellents, and gene drive technology (table 2).

Bait stations, also known as attractive targeted sugar baits, are hung on the outside walls of houses. Attractive targeted sugar baits contain an attractant, a feeding stimulant, and an active ingredient (toxin) that kills the feeding mosquito. Despite high expectations of effectiveness based on entomological data and modelling studies, a 2023 epidemiological trial did not provide evidence that attractive targeted sugar baits offer additional protection against malaria when co-deployed with IRS or ITNs.[63]

Eave tubes are plastic cylinders covered by a removable mesh with a static coating and a powder-formulated insecticide, which are installed in walls under the roof of a house to attract and kill mosquitoes that attempt to enter the house. Trials on the epidemiological effect of eave tubes are ongoing in Côte d'Ivoire and Uganda.[64]

Systemic endectocide treatment involves the mass administration of an endectocide to humans alone or to humans and livestock, to kill vectors that feed on these hosts, and thereby, suppress vector populations. Trials to evaluate the public health impact of this method so far have shown conflicting results,[65,66] whereas results from further trials in Mozambique and Kenya are awaited.[67]

Spatial repellents consist of emanators of a volatile compound that repels and kills mosquitoes in and around the house, thus reducing human–vector contact. One trial has shown a remarkable effect of this intervention on malaria,[68] and results from a further trial in Mali are awaited.[69]

Topical repellents are applied to the skin of individuals to protect them from bites of host-seeking mosquito vectors. Trials for evaluating the effect of topical repellents on malaria at the community level are at the planning stage.[70]

Gene drive technology aims to introduce genetically modified mosquitoes into wild *Anopheles* populations with the objective of causing infertility or feeding inability in female mosquitoes, thus reducing vector populations, and hence, malaria transmission. This technology has so far not been tested in field trials.[32,71]

Conclusions

The latest advice by the DDT expert group to the Conference of Parties is that the continued need for the use of DDT for malaria vector control is justified only in a few specific settings, which take into account the affordability and availability of alternatives to DDT, insecticide resistance management, and the need for disease outbreak response in the event that alternatives to DDT are unavailable.[11] Given the substantial reduction in the global production and use of DDT of late, coupled with the steady increase in the number of alternative IRS insecticides and ITN products, a global phase-out of DDT appears to be within reach.

Challenges in the global elimination of DDT are that most of the alternative insecticides are less affordable than DDT, local registration and supply chain management systems are in some instances slow in adapting to the procurement of alternatives, and supplies of alternatives are not necessarily guaranteed. The affordability issue is particularly important for South Africa, which depends exclusively on domestic funding for its IRS operations, with malaria control having to compete with various other public health programmes for the available funds. Another challenge is that global progress in malaria control and elimination has stagnated. In 2023, global funding for malaria control and elimination totalled US$4 billion, which falls short of the estimated US$8·3 billion for 2023 that is required to stay on track for the targets set in the WHO global technical strategy for malaria.[28] The funding gap, emphasised by the aid cuts made by the US Government in 2025, could be an impediment for some countries to shift to more costly alternatives to DDT for malaria vector control.

The intersessional consultation meetings with countries in the DDT Register have highlighted the pivotal role these meetings play in sharing experiences on the challenges and barriers that countries encounter in phasing out DDT or withdrawing from the DDT Register, or both. These meetings also serve to signal whether a country plans to revert to DDT so that timely support for alternatives can be explored. In retrospect, the phasing out of DDT since 2004 could have been faster had targeted support to specific countries (such as through the intersessional consultation meetings) been provided earlier.

India, previously the largest DDT user by far, has indicated that the country will no longer use DDT for disease vector control from April, 2025, but would still export DDT to countries with a continued demand for the insecticide.

In the southern African subregion, DDT continues to provide some countries with an affordable option for malaria vector control, wherein the chemical is used within insecticide resistance management strategies by rotation or mosaic deployment with alternative insecticides. Malaria vector populations in southern Africa have mostly remained susceptible to DDT, but signs show that DDT resistance is emerging across the subregion.

Zimbabwe continues to use DDT for malaria vector control. South Africa still uses DDT but plans to shift to alternatives as soon as possible, depending on affordability and product availability. Eswatini is keeping DDT for emergency malaria control, whereas Botswana, Namibia, and Zambia are shifting away from using DDT pending formal policy change. These southern African countries have requested support for the registration, subregional harmonisation, local evaluation, and uptake of new IRS products or ITNs, or both, to replace DDT. Considering the challenges encountered with respect to the affordability and availability of DDT alternatives, coordination at the subregional level will be crucial. Without external support, some countries might continue to use DDT for as long as local vector populations remain susceptible and so long as DDT is being supplied by the producer or from other stocks or sources. Hence, the development of a subregional initiative to support the last few DDT-using countries in the transition to alternative IRS or ITN products (or both) within their insecticide resistance management strategies is recommended.[11]

Several countries across regions have reported concerns about obsolete stockpiles of DDT and DDT waste, which pose a threat to human health and the environment and need environmentally sound disposal. Concerns also exist about anecdotal reports of illegal trade and use of DDT. Although the environmental and health risks due to DDT are well documented, far less is known regarding the negative effects related to the deployment of alternatives to DDT. Examples of such concerns are the shortage of strategies for environmentally sound disposal of worn-out ITNs that are no longer used and the possible harms caused by the latest insecticidal products. These issues require attention from the international community.

Although the hurdles discussed herein remain to be overcome, the downward trajectory of DDT production and use signals that the global phasing out of DDT is reaching its last mile.

Contributors

HvdB, RSY, and IK conceived the Personal View. HvdB drafted the manuscript, conducted the data collection, data cleaning, visualisation, and analysis. All authors conducted the interpretation of data as members or participants of the DDT expert group. HvdB and IK assessed and verified the data reported in the manuscript. All authors contributed to the manuscript and read and approved the final version.

Declaration of interests

HvdB, HRA, BDB, TJ, SHPPK, NSM, YRP, and IK are members of the DDT expert group under the Stockholm Convention on Persistent Organic Pollutants and HvdB was previously engaged as a consultant in preparation of the reports of DDT expert group meetings. RSY participated as a WHO staff in a DDT expert group meeting and declares no conflict of interests. LEF declares no actual or perceived conflict of interests. Any studies and other information referred to in this paper do not necessarily reflect the views of the Stockholm Convention Secretariat, the UN Environment Programme, or the UN. The designations used and the presentation of the material in such studies and references do not imply the expression of any opinion whatsoever on the part of the Secretariat, UN Environment Programme, or the UN, concerning geopolitical situations or the legal status of any country, territory, area, or city, or its authorities.

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