

## **7.2 Environmental degradation, residue, and ecological impact**

Pesticide residues persist widely in soils, water bodies, sediments, crops, air, and indoor dust environments due to intensive agricultural and vector control applications. Monitoring studies reveal that a majority of environmental samples contain multiple pesticide residues at varying concentrations, including both approved and non-approved compounds. These residues contribute to contamination of food chains and drinking water sources with potential human health implications. The presence of complex mixtures complicates risk assessments since interactions among chemicals may amplify toxic effects beyond those predicted for individual substances (Damalas and Eleftherohorinos, 2011; Silva et al., 2023). Although newer pesticides tend to be more biodegradable than legacy compounds, their degradation products can still affect soil microbiota and aquatic ecosystems adversely if not properly managed (Carvalho, 2017; Suarez et al., 2025).

Efforts to reduce environmental contamination focus on improving pesticide formulations and application techniques alongside promoting alternative pest management strategies. Sustainable agriculture practices such as organic farming or integrated pest management reduce reliance on chemical inputs while enhancing ecosystem resilience. Additionally, regulatory policies increasingly call for comprehensive environmental risk evaluations that include persistence data and ecotoxicity profiles during product approval processes. These measures aim to minimize long-term ecological damage while ensuring effective vector control interventions remain available (Carvalho, 2017; Giovagnoni et al., 2025).

## **7.3 Cost-effectiveness and long-term sustainability**

Assessing the cost-effectiveness of mosquito control strategies requires balancing immediate public health benefits against potential environmental costs and sustainability considerations. While chemical insecticides often provide rapid reductions in vector populations at relatively low initial costs, their long-term use can lead to resistance development, non-target toxicity, and environmental degradation that undermine overall program success (Damalas and Eleftherohorinos, 2011; Hauschild et al., 2022). Incorporating sustainability metrics into decision-making frameworks helps identify interventions that optimize health outcomes without compromising ecosystem integrity or future resource availability.

Sustainable vector management increasingly integrates economic analyses with environmental risk assessments to support safe-and-sustainable-by-design approaches. This combined evaluation facilitates robust policy decisions by highlighting trade-offs between efficacy, safety, cost, and ecological impact throughout a product's lifecycle. Moreover, expanding benefit-risk assessments to include environmental data enables healthcare providers and policymakers to select interventions that align with planetary health goals while maintaining disease control effectiveness (Hauschild et al., 2022; Giovagnoni et al., 2025). Ultimately, fostering multi-sectoral collaboration and investing in innovative technologies will be critical for achieving durable malaria transmission reduction within sustainable development frameworks.

## **8 Discussion and Future Perspectives**

Integrated vector management (IVM) strategies that combine multiple control methods have demonstrated significant potential in reducing malaria transmission, particularly in high-burden regions such as sub-Saharan Africa. Systematic reviews indicate that combining insecticide-treated nets (ITNs), indoor residual spraying (IRS), larval source management, and environmental modifications results in greater reductions in malaria incidence and mosquito density compared to single interventions. These integrated approaches address different mosquito life stages and behaviors, enhancing overall effectiveness and mitigating the limitations of individual methods. Moreover, the use of advanced surveillance tools, including molecular diagnostics and geographic information systems (GIS), supports targeted deployment of interventions, improving resource allocation and program outcomes. Despite these successes, the heterogeneity of local ecological and social contexts means that integrated strategies must be tailored to specific settings for optimal impact. Evidence suggests that community engagement and multisectoral collaboration are critical components that enhance uptake and sustainability of interventions. Additionally, integrating novel technologies such as genetically modified mosquitoes or Wolbachia-infected