limitations inherent in single-method approaches, including insecticide resistance and behavioral adaptations by vectors (Abbasi, 2025). The integration model also supports the inclusion of novel genomic tools like gene drives alongside traditional interventions to achieve sustainable reductions in disease transmission.

Successful multi-strategy models require robust surveillance systems to guide targeted interventions based on local entomological and epidemiological data. Frameworks like Integrated Aedes Management (IAM) exemplify this approach by incorporating integrated vector surveillance, community mobilization, intersectoral collaboration, capacity building, research, advocacy, and supportive policies. These pillars ensure that diverse tools are deployed effectively according to risk scenarios while fostering adaptability and sustainability in vector control programs (Beier et al., 2008; Roiz et al., 2018).

### 6.3 Community participation and public health policy support

Community participation is fundamental to the success of IVM as it fosters local ownership, enhances compliance with control measures, and facilitates sustainable behavior change. Engaging communities through education campaigns, social mobilization events such as “mosquito days,” and involvement in environmental management activities empowers residents to contribute actively to vector reduction efforts. Partnerships with local organizations and government departments further strengthen these initiatives by integrating income-generating activities like fish farming or tree planting that align with vector control goals (Ng’ang’a et al., 2021; Ni et al., 2025). Such multisectoral collaboration enhances resource mobilization and capacity building at the grassroots level.

Public health policy support is equally critical for institutionalizing IVM frameworks within national malaria control programs. Strong leadership from governments ensures sustained funding, regulatory backing for innovative tools, and coordination across sectors involved in vector management. Policies aligned with global strategies like the WHO Global Vector Control Response provide guidance for scaling up integrated approaches while addressing emerging challenges such as insecticide resistance or climate change impacts (Roiz et al., 2018; Tourapi and Tsioutis, 2022). Together with community engagement, supportive policies create an enabling environment for effective implementation of IVM strategies that reduce malaria transmission risk sustainably (Beier et al., 2008; Ni et al., 2025).

## 7 Safety, Environmental Impact, and Sustainability Assessment

### 7.1 Toxicity to non-target organisms and ecological risks

The use of pesticides in mosquito control poses significant risks to non-target organisms across terrestrial and aquatic ecosystems. Studies have documented adverse effects on growth, reproduction, behavior, and physiological functions in a wide range of species including invertebrates, vertebrates, plants, and microorganisms. These negative impacts contribute to biodiversity loss and ecosystem disruption, with insecticidal compounds such as neonicotinoids notably affecting amphibians and other sensitive taxa. The severity of these effects varies by region but remains consistent across different environments even under realistic exposure scenarios, raising concerns about the sustainability of current pesticide practices (Silva et al., 2023; Wan et al., 2025). Furthermore, natural bioherbicides like matricaria lactones show variable toxicity profiles; while they degrade rapidly in the environment, they can still pose acute risks to aquatic organisms through runoff or leaching, indicating that even plant-based alternatives require careful ecotoxicological evaluation (Suarez et al., 2025).

Ecological risk assessments increasingly emphasize the need to consider indirect effects on food webs and ecosystem services alongside direct toxicity. Emerging methodologies advocate integrating molecular to ecosystem-level endpoints to better capture the complex consequences of pesticide exposure on wildlife populations. However, regulatory frameworks often lag behind scientific advances in assessing these broader ecological impacts comprehensively. This gap underscores the importance of developing more holistic risk assessment approaches that incorporate both standard toxicity data and novel biomarkers to safeguard biodiversity while maintaining vector control efficacy (Rattner et al., 2023; Wan et al., 2025).