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INSECTICIDE RESISTANCE IN MOSQUITO VECTORS IN NIGERIA: A GEOSPATIAL REVIEW OF PUBLISHED EVIDENCE

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ABSTRACT

Insecticide resistance among mosquito vectors poses a significant threat to the sustainability of malaria control and other vector-borne disease elimination programs. This study systematically collated and analyzed published data on insecticide resistance monitoring in Nigeria from 2007 to 2025, covering 54 studies across 180 unique locations. Data were synthesized to examine temporal trends, geospatial distribution, and resistance mechanisms across mosquito genera and four major insecticide classes. The findings reveal widespread resistance across Nigeria, with pyrethroids—the cornerstone of long-lasting insecticidal nets (LLINs)—being the most frequently tested and most resisted class. Pockets of susceptibility to pyrethroids were observed in limited areas of southern Nigeria (Lagos, Ondo, and Delta States). Resistance to carbamates, organochlorines, and organophosphates was also documented, though organophosphates were the least studied. Genus-specific analysis demonstrated that *Anopheles*, *Culex*, and *Aedes* mosquitoes all exhibited resistance, with *Anopheles* showing the broadest geographic spread. Mechanistic data highlighted a predominant role of metabolic resistance, often occurring alone or in combination with knockdown resistance (kdr) mutations, although kdr mutations were particularly notable in *Culex* populations and in selected *Anopheles* populations in southwestern and northeastern regions. These findings underscore the urgent need to strengthen insecticide resistance surveillance and integrate resistance management strategies into malaria control programs in Nigeria. The widespread loss of susceptibility to pyrethroids highlights the importance of transitioning to next-generation vector control tools, diversifying insecticide use, and investing in novel interventions. Continuous monitoring and operational research are critical to inform evidence-based vector control policies and safeguard public health gains.

Keywords: Insecticide resistance, Resistance mechanism, Pyrethroids, GIS, Nigeria

INTRODUCTION

Mosquito-borne diseases remain one of the most pressing public health challenges in sub-Saharan Africa, with Nigeria bearing a disproportionately high share of the burden (Adeleke *et al.,* 2025, Oladipo, 2022). Malaria alone accounts for many outpatient visits, hospitalizations, and childhood deaths in the country, contributing significantly to maternal and child morbidity and mortality (Babalola *et al.,* 2021; WHO, 2018). Beyond malaria, other mosquito-borne illnesses such as lymphatic filariasis, yellow fever, dengue, and chikungunya (Babalola *et al.,* 2025) continue to affect millions of people, posing an additional strain on the health system. The consequences of these diseases extend well beyond health, resulting in productivity losses, school absenteeism (Babalola *et al.,* 2021), reduced agricultural output, and considerable economic costs to households and the nation at large (Adewale *et al.,* 2016). Thus, effective mosquito control remains a critical pillar of public health strategy in Nigeria and across Africa.

Vector control has historically played a central role in reducing disease transmission, with interventions such as long-lasting insecticidal nets (LLINs), indoor residual spraying (IRS), and larval source management proving effective in reducing vector densities and malaria prevalence (Adeogun *et al.,* 2023; Adeogun *et al.,* 2025a). These tools, particularly LLINs and IRS, are highly dependent on insecticidal efficacy, and their widespread distribution has contributed to notable declines in malaria morbidity and mortality in many endemic regions (WHO, 2018). However, the growing challenge of insecticide resistance in mosquito populations is now threatening these hard-won gains (Adeogun *et al.,* 2023). Resistance undermines the effectiveness of standard control measures, potentially reversing progress towards malaria elimination and exacerbating the risk of resurgence of other arboviral and parasitic diseases.

In Nigeria, insecticide resistance has been documented across different mosquito genera—most prominently *Anopheles* (malaria vector), but also *Aedes* (vectors of arboviruses such as yellow fever and dengue) and *Culex* (vectors of filariasis and nuisance biting) (Babalola *et al.,* 2025). Resistance has been detected against all four major classes of insecticides (pyrethroids, carbamates, organophosphates, and organochlorines) posing a serious barrier to sustained vector control (Chukwuekezie*et al.,* 2020; Busari *et al.,* 2023; Olayinka *et al.,* 2024). Pyrethroid resistance, in particular, is of great concern given the heavy reliance on LLINs, which use this class of insecticide exclusively (Adeogun *et al.,* 2023). Furthermore, resistance is driven by multiple mechanisms, including target-site mutations such as knockdown resistance (kdr) and metabolic detoxification involving cytochrome P450 monooxygenases, esterases, and glutathione S-transferases (Adeogun *et al.,* 2025b; Fagbohun *et al.,* 2020; Nouage*et al.,* 2020). The coexistence of multiple mechanisms within vector populations complicates management strategies and limits the available options for insecticide rotation or combination approaches.

Despite the increasing number of studies on insecticide resistance in Nigeria, the available evidence remains fragmented, localized, and heterogeneous across states, ecological zones, and mosquito species. Data are often limited to specific sentinel sites, with few studies designed to generate nationally representative patterns. This patchwork of findings makes it difficult for policymakers and vector control programs to fully understand the scale and dynamics of resistance, or to make informed decisions about alternative interventions such as next-generation LLINs, synergist-based nets, or integrated vector management approaches.

A systematic synthesis of the available evidence is therefore urgently needed to provide a comprehensive national picture of insecticide resistance in Nigeria. By collating and mapping published data across time and space, this review seeks to describe the temporal and spatial trends in mosquito resistance, highlight the distribution of key resistance mechanisms, and identify critical knowledge gaps. Such an evidence base is essential to guide national malaria and vector control programs, inform insecticide resistance management strategies, and prioritize research and surveillance investments. Ultimately, strengthening the evidence on insecticide resistance will be vital to sustaining vector control, reducing the burden of mosquito-borne diseases, and moving Nigeria closer to its goals of malaria elimination and improved population health.

MATERIALS AND METHODS

Literature Search and Data Extraction

We conducted a review of published studies that reported insecticide resistance in mosquito populations in Nigeria. Relevant articles were identified through database searches, screening of reference lists, and grey literature review. Studies were included if they provided data on the susceptibility or resistance status of mosquito genera (*Anopheles*, *Aedes*, and *Culex*) to at least one insecticide class (pyrethroids, carbamates, organophosphates, or organochlorines). Where reported, resistance mechanisms such as kdr mutations and metabolic resistance were also extracted. From each eligible study, we extracted publication year, study location, mosquito genus, insecticide class, resistance status, and mechanism. These data were compiled into a structured Excel spreadsheet. Geographic coordinates (latitude and longitude) were obtained directly from the studies or approximated using reported town or village names to facilitate spatial mapping.

Data Processing and Visualization

The dataset was imported into R (version 4.4.3) for processing and analysis. Data restructuring and cleaning were performed using the dplyr and tidyr packages (Adeogun *et al.,* 2025), while geographic information was managed using the sf package. Administrative boundaries of Nigeria were sourced from publicly available shapefiles to provide spatial context.

Resistance data were converted into long format and visualized using ggplot2. Point-level data were plotted on Nigeria's state boundaries, with mosquito genera, insecticide classes, and resistance mechanisms represented by distinct shapes, colors, and facets. Faceted maps enabled side-by-side comparison across mosquito groups and insecticide classes, while temporal mapping illustrated changes in resistance status over time. The analysis was descriptive in nature, and findings were summarized using figures rather than inferential statistics.

RESULTS AND DISCUSSION

Data summaries

A total of 54 studies conducted across 180 unique locations were retrieved from the published literature. The annual distribution of insecticide resistance monitoring studies in Nigeria between 2007 and 2025 is presented in Figure 1. The majority of studies focused on *Anopheles* mosquitoes, followed by *Culex*, while relatively few investigations targeted *Aedes* mosquitoes. Notably, most studies on *Aedes* and *Culex* were conducted between 2020 and 2025 (Figure 1). In terms of insecticide classes, pyrethroids were the most frequently tested, followed by organochlorines, whereas organophosphates were the least evaluated (Figure 2).

Geospatial Distribution and Status of Insecticide Resistance to Four Classes of Insecticides in Nigeria

The overall insecticide resistance status of mosquitoes to four major classes of insecticides in Nigeria is presented in Figure 2. The findings indicate widespread resistance across the country, with only a few localized areas demonstrating susceptibility to pyrethroids (permethrin, deltamethrin, and alpha-cyhalothrin) and suspected resistance to carbamates (propoxur and bendiocarb), particularly in the southern regions.

The insecticide resistance status of mosquito genera in relation to the four classes of insecticides is shown in Figure 3. All three genera (*Anopheles, Aedes,* and *Culex*) exhibited widespread resistance to all insecticide classes, with limited exceptions. Notably, small pockets of susceptibility to pyrethroids were observed in southern Nigeria: *Anopheles* in Lagos, Ondo, and Delta States; *Aedes* in Lagos; and *Culex* also in Lagos.

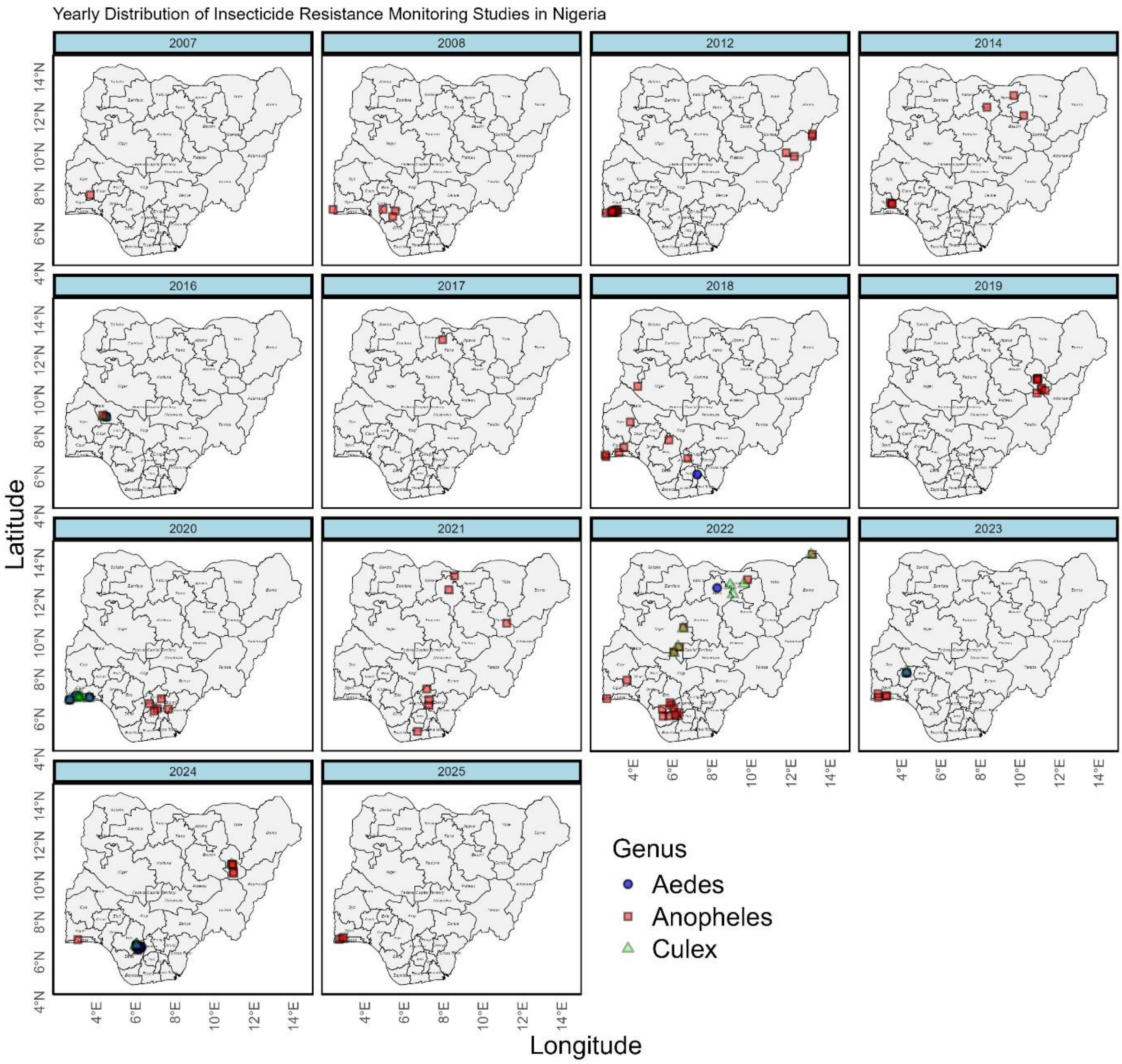

Figure 1: The annual distribution of insecticide resistance monitoring studies in Nigeria between 2007 and 2025

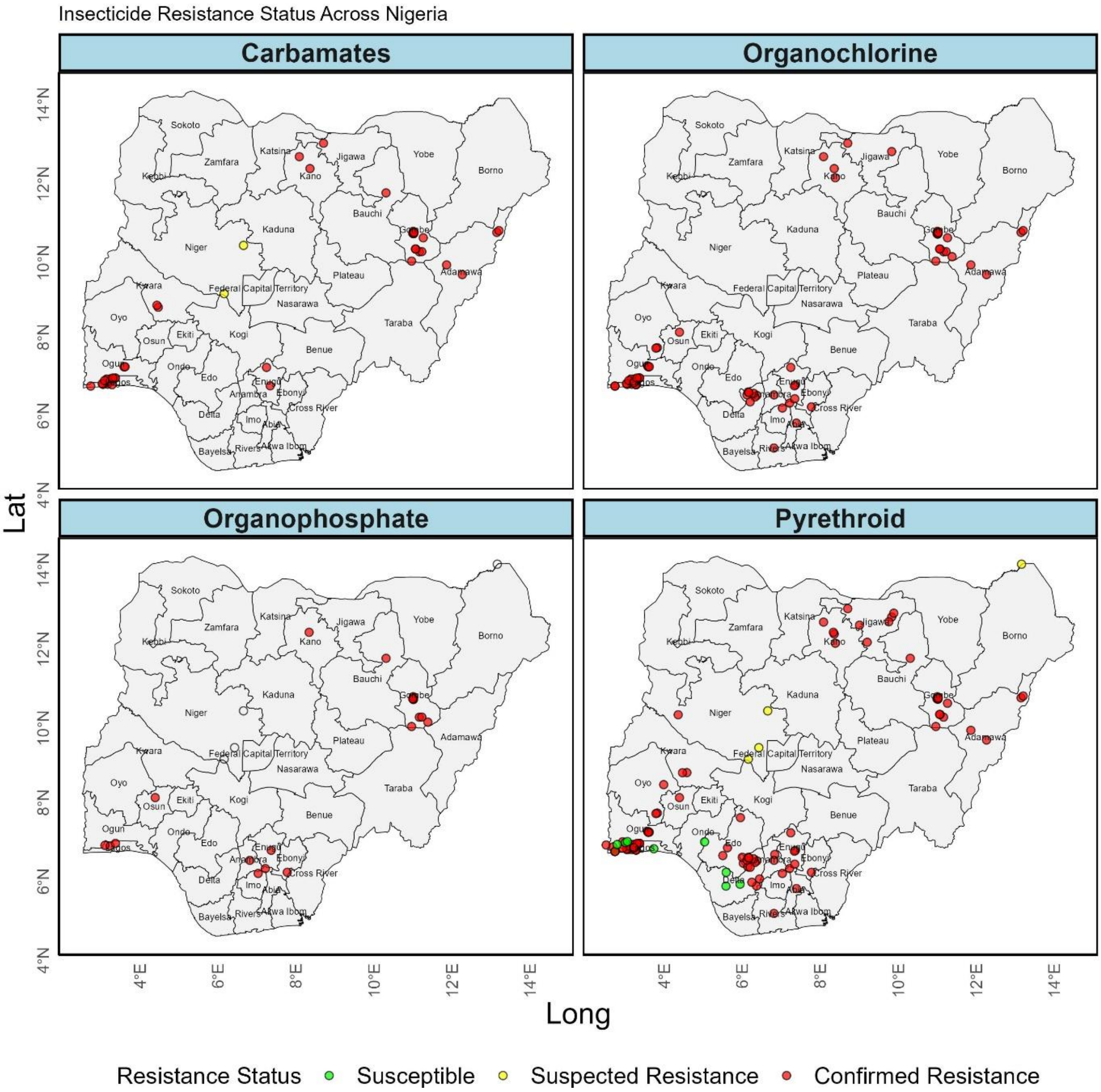

Figure 2: Overall insecticide resistance status of mosquitoes to four classes of insecticides in Nigeria

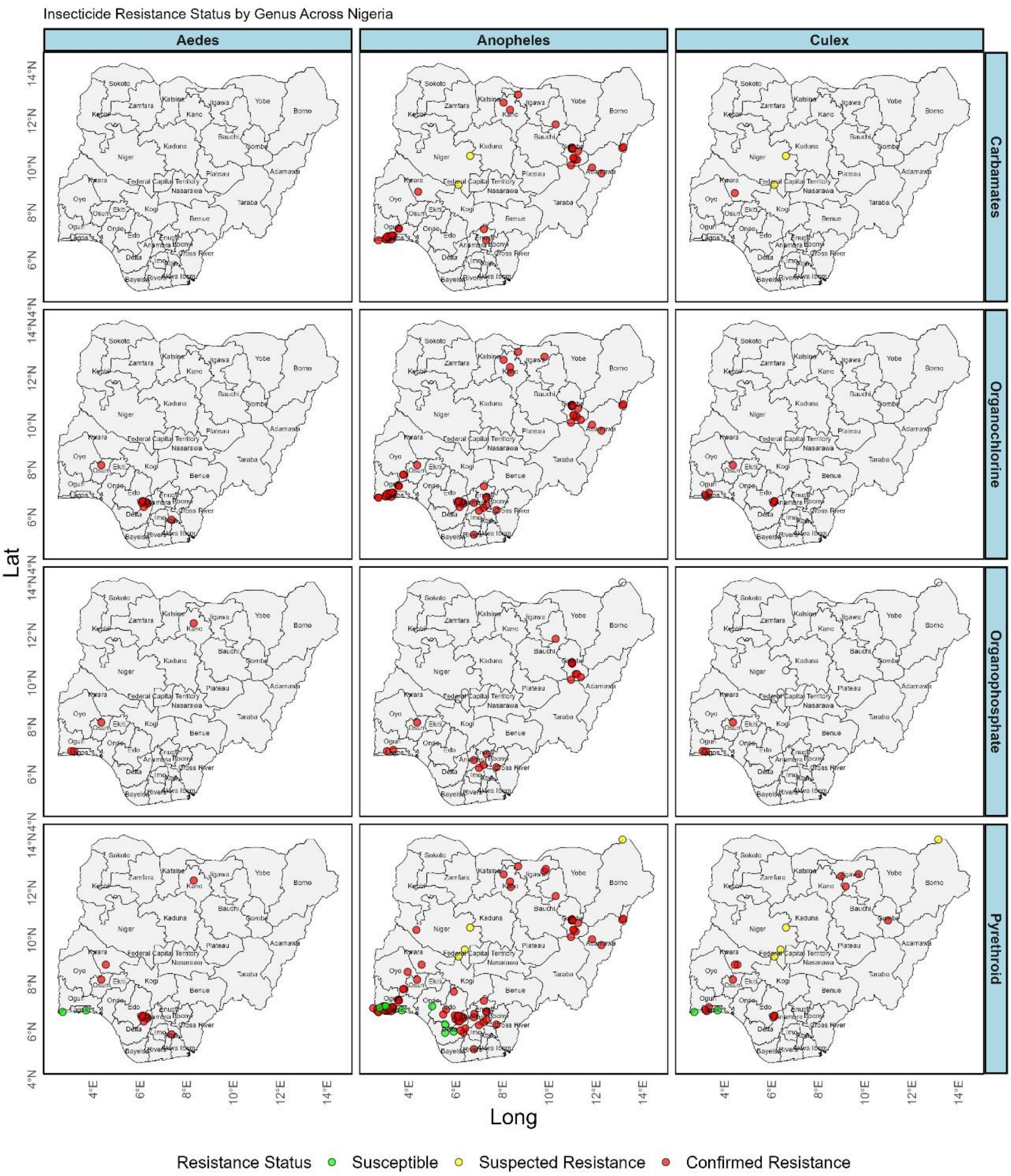

Figure 3: Insecticide resistance status of mosquitoes to four classes of insecticides by genus in Nigeria

Mechanisms of resistance to different classes of insecticides in mosquitoes across Nigeria

The results showing overall mechanisms of mosquito resistance to four classes of insecticides in Nigeria is presented in figure 4. The results showed that metabolic resistance is generally involved more singly and then in combination with KDR in most parts of the country (Figure 4). However, knockdown resistance gene mutations were also recorded in some part of the southwestern part of the country as well as the Northeastern part of the country (Figure 4).

The results showing insecticide resistance mechanism of mosquitoes to four classes of insecticides by genus in Nigeria is presented in Figure 5. The results showed that the Anopheles mosquitoes demonstrated more of metabolic resistance mechanism across all the classes of insecticides (except for organophosphate which is more of kdr mutation) compared to other genus. Furthermore, while resistance to carbamate, organophosphate and organochlorine in *Culex* spp seems to be mainly driven by kdr mutation in Nigeria, metabolic mechanism seems to play more role in their resistance to pyrethroid insecticides. On the other hand, the results suggest that the resistance showed by *Aedes* mosquitoes across all the insecticide classes in few areas documented in the country were probably mostly driven by metabolic resistance mechanism (Figure 5).

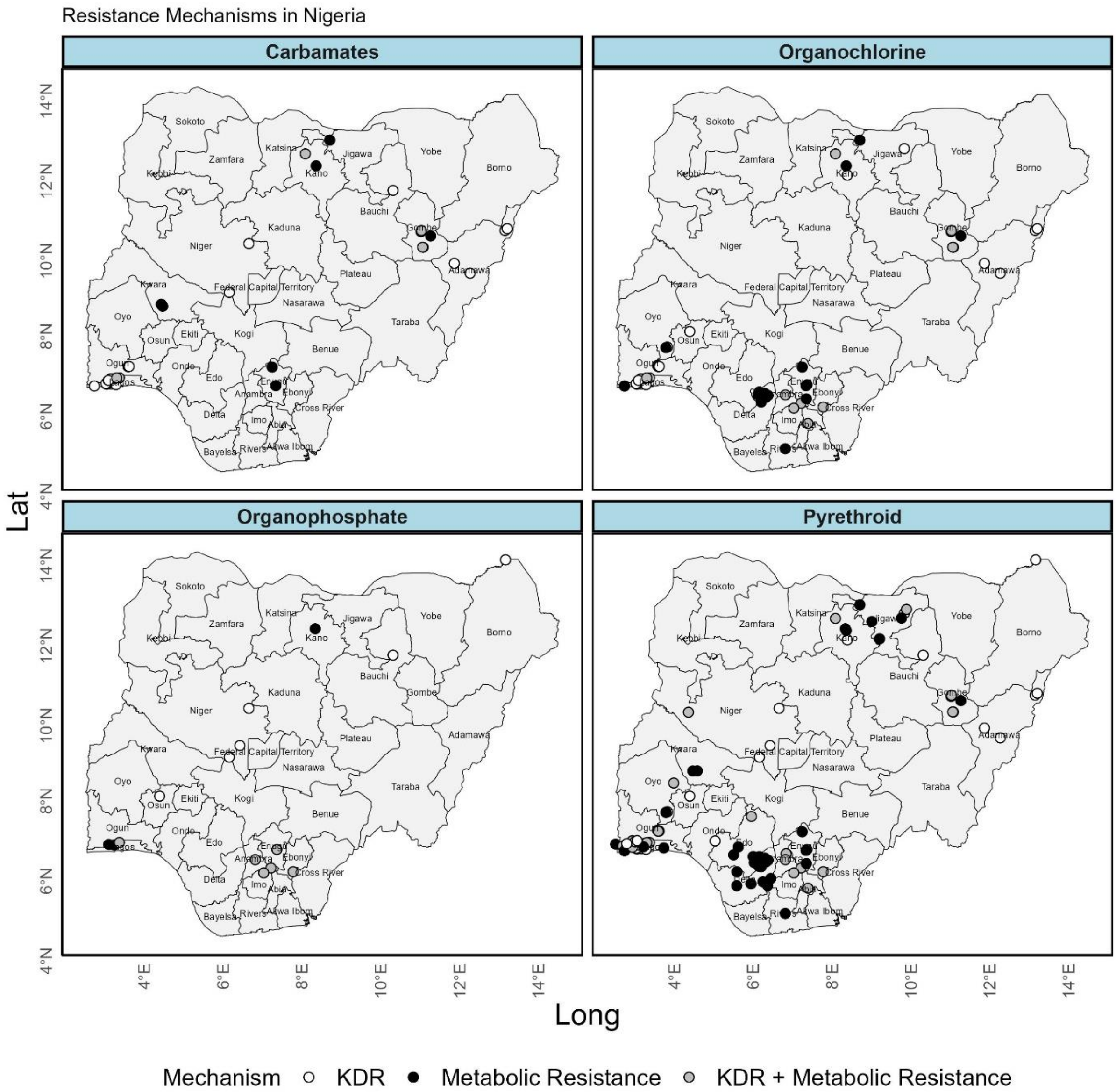

Figure 4: Overall mechanisms of mosquito resistance to four classes of insecticides in Nigeria

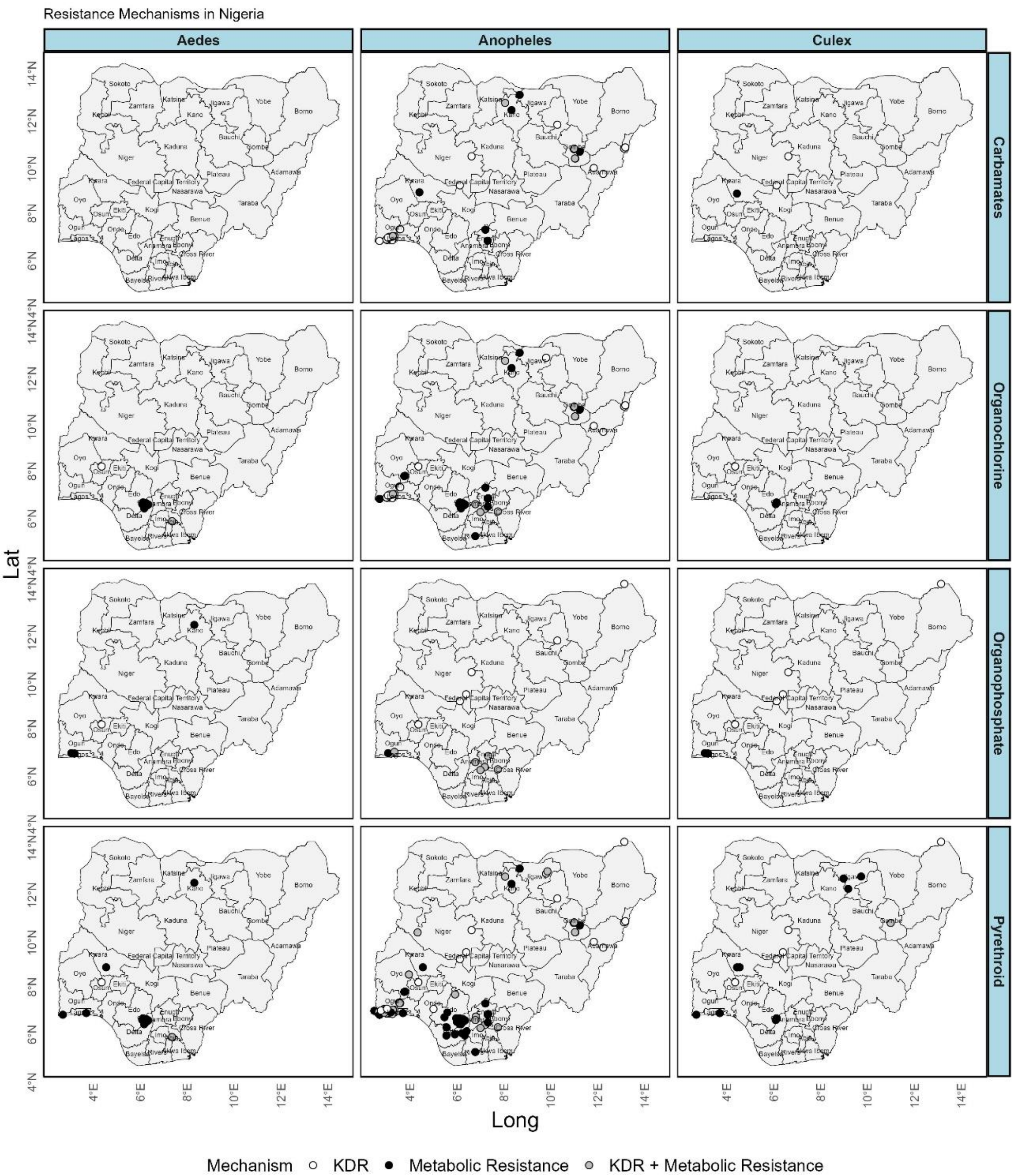

Figure 5: Insecticide resistance mechanism of mosquitoes to four classes of insecticides by genus in Nigeria

Discussion

This review highlights the widespread occurrence of insecticide resistance in mosquito populations across Nigeria, with important implications for malaria control, arboviral disease prevention, and public health policy. A total of 54 studies covering 180 unique locations were retrieved, spanning from 2007 to 2025. The evidence demonstrates a clear predominance of insecticide resistance monitoring efforts in *Anopheles* mosquitoes, reflecting their central role as malaria vectors, while comparatively fewer studies targeted *Culex* and *Aedes* species. Interestingly, most studies on *Culex* and *Aedes* were conducted between 2020 and 2025, suggesting a growing recognition of their roles in transmitting arboviruses such as lymphatic filariasis, dengue, and yellow fever.

Across Nigeria, resistance was reported in all three genera of mosquitoes to the four major classes of insecticides (pyrethroids, organochlorines, carbamates, and organophosphates). Pyrethroid resistance was the most widespread, consistent with findings across sub-Saharan Africa (Hemingway et al., 2016; Ranson and Lissenden, 2016). This is unsurprising, given the extensive reliance on pyrethroids in long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS). Although pockets of susceptibility to pyrethroids were observed in some southern states such as Lagos, Ondo, and Delta, these were limited exceptions. Resistance to carbamates and organophosphates was less widely documented but nevertheless present, underscoring the shrinking arsenal of fully effective insecticides.

The geospatial mapping of resistance patterns reveals a concerning picture: resistance is not localized but widespread across Nigeria. This has critical implications for malaria control programmes, which continue to rely heavily on pyrethroid-based LLINs as a frontline intervention (WHO, 2022). The presence of resistance in *Anopheles* populations threatens to reduce the effectiveness of LLINs and IRS, potentially undermining progress towards malaria elimination goals. In addition, resistance in *Culex* and *Aedes* raises public health concerns for the control of arboviral and filarial diseases, which already place substantial burdens on communities.

Mechanistically, both target-site mutations (e.g., knockdown resistance [kdr]) and metabolic resistance mechanisms were implicated across mosquito genera. In *Anopheles*, metabolic resistance predominated across most insecticide classes, while kdr mutations were particularly associated with resistance to organophosphates. In *Culex*, kdr mutations played a dominant role in resistance to carbamates, organophosphates, and organochlorines, whereas metabolic mechanisms were more prominent in pyrethroid resistance. For *Aedes*, resistance appeared to be mainly metabolically driven in the few areas where studies were available. These findings are consistent with global patterns of resistance evolution, where mosquitoes often exhibit multiple mechanisms acting simultaneously, complicating control strategies (Riveron et al., 2014; 2019; Moyes *et al*., 2017).

From a public health perspective, these findings emphasize the urgent need for insecticide resistance management strategies in Nigeria. Rotational use of insecticides with different modes of action, deployment of next-generation LLINs (e.g., pyrethroid–piperonyl butoxide [PBO] nets or dual active ingredient nets), and integrated vector management (IVM) approaches are necessary to preserve the efficacy of interventions (WHO, 2012; Churcher *et al.,* 2016; Adeniyi *et al.,* 2024). Policy makers should also consider strengthening entomological surveillance systems to ensure timely detection of resistance trends and mechanisms. This would enable evidence-based decision making and more targeted vector control interventions at both local and national levels.

Finally, the limited number of studies on *Aedes* and *Culex* mosquitoes highlights a major research gap. Given the rising threat of arboviral epidemics in Africa, future studies should systematically monitor resistance in these genera to guide preparedness and response efforts. Furthermore, the integration of geospatial tools, as demonstrated in this review, provides a valuable platform for tracking resistance over time and space. Future research should build on this by incorporating predictive modeling of resistance dynamics, evaluating the operational impact of resistance on intervention effectiveness, and testing innovative control tools such as biological and genetic approaches.

This review has several limitations. The synthesis is constrained by the availability and quality of published studies, which varied in methodology, diagnostic protocols, sample sizes, and reporting standards. Certain regions of Nigeria were underrepresented, resulting in uneven geographic coverage. In some cases, geographic coordinates were estimated from reported locations, which may have introduced minor positional inaccuracies. Furthermore, variations in insecticide concentrations and susceptibility testing methods across studies limit direct comparability of findings. Finally, restricting the review to published studies raises the possibility of publication bias. Despite these limitations, the review provides a valuable national overview of insecticide resistance in mosquito vectors and offers important insights into spatial and temporal resistance patterns in Nigeria.

CONCLUSION

We have mapped a comprehensive status of mosquito insecticide resistance in Nigeria from the available literature and synthesized it into a single document to support policymakers in making informed decisions.The widespread insecticide resistance observed in Nigerian mosquito populations poses a significant challenge to vector control and malaria elimination goals. Addressing this requires a multifaceted strategy that combines surveillance, policy action, and the development of novel interventions to sustain progress in malaria and arbovirus control.

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