

The Biodiversity of *Anopheles* and Malaria Vector Control in Indonesia: A Review

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Abstract. Malaria is a re-emerging vector-borne disease. Malaria is caused by *Plasmodium* parasites namely *P. falciparum*, *P. malariae*, *P. vivax*, *P. ovale*, and *P. knowlesi*. The parasite is transmitted by mosquitoes from the genus *Anopheles*. The genus *Anopheles* comprises more than 480 described species worldwide and many more are yet to be described. It is known that there are more than 100 species of *Anopheles* that can transmit malaria parasites to humans. The present review aims to assess studies on the biodiversity of *Anopheles* as a malaria vector and its control in Indonesia. The results showed that a total of 80 species of *Anopheles* mosquitos are reported in Indonesia, and at least 31 species of *Anopheles* mosquitoes have been reported as malaria vectors in Indonesia. Several efforts to decrease the number of malaria cases are the distribution and wide-scale use of Long-Lasting Insecticide Treated Bednets (LLIN), Indoor Residual Spraying (IRS) applications, larvae control, and environmental management. Vector control and entomological surveillance of malaria are one of the main domains for achieving malaria elimination. In conclusion, a combination of national policies, local-specific, habitat-specific, and community participation approaches are needed for effective malaria vector control in Indonesia.

1 Introduction

Malaria is a re-emerging disease transmitted by vector insects (vector-borne disease). This infectious disease is common in the tropics and is characterized by symptoms such as fever with frequent temperature changes, anemia, an enlarged spleen, and the presence of pigment in the tissues. 5 *Plasmodium* parasite species cause malaria in humans and 2 of these species – *P. falciparum* and *P. vivax* – pose the greatest threat. *P. falciparum* is the deadliest malaria

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parasite and the most prevalent on the African continent. *P. vivax* is the dominant malaria parasite in most countries outside of sub-Saharan Africa. The other malaria species that can infect humans are *P. malariae*, *P. ovale*, and *P. knowlesi* [1].

Malaria cases reached 249 million in 2022, up from 244 million in 2021. Malaria deaths were estimated to reach 608,000 in 2022, lower than in 2021 which was 610,00. In 2022 malaria cases in Indonesia rank second after India in Southeast Asia, with 443,530 [2, 3].

Malaria control efforts have been carried out by the Government of Indonesia continuously with a target of eliminating this disease by 2030. In 2009, the Indonesian Ministry of Health issued a Decree of the Minister of Health Number 293 of 2009 in an effort to strengthen the malaria elimination program. The elimination achievements at the district/city level in 2018 were 285 districts/cities. The process was preceded by an elimination assessment for Java and Bali in 2023; an assessment for Sumatra, NTB, and Sulawesi in 2025; an assessment for Kalimantan and North Maluku in 2027; an assessment for NTT and Maluku in 2028 and an assessment for West Papua and Papua in 2029 and national elimination certification in 2030 [4].

The strategy to break the chain of transmission is vector control, early case detection, appropriate case management, and prompt treatment. However, efforts to detect malaria cases are often delayed. In addition, consumption of anti-malarial drugs that are still not standardized by the public and the presence of non-standard malaria drugs that are sold freely in stalls and pharmacies in high endemic areas in Indonesia are still obstacles and challenges in accelerating efforts to control this disease. The challenge of vector and parasite resistance is a problem faced in malaria control [5]. Malaria Vector control is one of the malaria prevention and control methods that tries to disrupt the malaria transmission chain. Vector control refers to efforts taken against disease vectors in order to minimize their potential to transmit parasites by protecting regions known to be receptive to transmission [6].

More than 480 species of the genus *Anopheles* have been identified globally [7] and many more yet to be described. More than 100 *Anopheles* species are known to be capable of transmitting malaria parasites to people. Only a few species, some of which are part of the species complex, are recognized as major vector species [8-10]. A range of factors influence *Anopheles* mosquitoes' vectorial potential as malaria vectors, which can be roughly classified as environmental, biological, or behavioral. *Anopheles* mosquitoes flourish in warm, humid areas. For example, environmental factors, temperature, rainfall, humidity, and seasonal fluctuations all influence mosquito abundance, longevity, and reproductive rates, hence impacting their vectorial capacity. Biological factors such as vector competence mean *Anopheles* mosquitos' ability to become infected with the malaria parasite (*Plasmodium* spp.) and spread it to humans. Vector competence is controlled by both genetic and environmental factors in mosquito populations, such as temperature and humidity. Interactions between *Anopheles* mosquitoes and Plasmodium parasites can alter the transmission dynamics of malaria. Parasite species, strain, and infection incidence in human hosts can all have an impact on the effectiveness with which *Anopheles* vectors transmit infection. Human hosts' presence and density have a direct impact on *Anopheles* mosquitoes' feeding behavior and blood meal preferences. High human population density increases the possibility of mosquito-human contact, which aids in malaria transmission. *Anopheles* mosquitoes have distinct behaviors that determine their vectorial potential, such as host-seeking, resting preferences, and feeding patterns. Indoor eating and resting patterns, for example, raise the risk of malaria transmission in human communities [11].

The present review aims to assess studies on the biodiversity of *Anopheles* as a malaria vector and its control in Indonesia. Information on the biodiversity of malaria vector species is very important because each species has a different habitat, behavior and different vectorial capacity. This will be very useful in supporting efforts to control malaria vectors that are more effective and on target.

2 Materials and methods

The method used was descriptive observational in the form of a literature review. Article searches were conducted on the NCBI database, PubMed, Springer, Elsevier, The Lancet database and the Indonesian repository site (neliti.com and Garuda Portal). Full-text articles in English or Indonesian published between 2012 and 2023, observational study design, and coverage of biodiversity, bionomic *Anopheles*, malaria control, and vector control were among the inclusion criteria. The literature review comprised 60 papers from several regions in Indonesia.

3 Results and discussion

3.1 The biodiversity of *Anopheles* as malaria vector in Indonesia

The results showed that a total of 80 species of *Anopheles* mosquitos are reported in Indonesia, and at least 31 species of *Anopheles* mosquitoes have been reported as malaria vectors in Indonesia [12, 13]. Some of the *Anopheles* species that act as vectors are members of the sibling species complex, taxa that are genetically closely related, but have morphological characters that cannot be distinguished from one another. Differences in the behavior of *Anopheles* mosquitoes belonging to the species complex can affect the ability of each species to transmit the malaria parasite [14, 15]. *Anopheles* species confirmed as malaria vectors and in Indonesia can be seen in Table 1.

Table 1. *Anopheles* species confirmed as malaria vector in Indonesia [3, 16]

No	<i>Anopheles</i> Species	Location confirmed as malaria vector
1	<i>Anopheles aconitus</i>	Java, Sumatera,
2	<i>An. balabacensis</i>	Java, Sumatera, West Nusa Tenggara (NTB), Kalimantan
3	<i>An.bancrofti</i>	Papua, West Papua
4	<i>An.barbirostris</i>	Sulawesi, West Nusa Tenggara (NTB), East Nusa Tenggara (NTT)
5	<i>An. barbumbrosus</i>	Sulawesi
6	<i>An. flavirostris</i>	Java, Bali, Sulawesi, East Nusa Tenggara (NTT)
7	<i>An. karwari</i>	Papua, West Papua
8	<i>An. kochi</i>	Java, Bali, Sumatera, Sulawesi, North Maluku, Maluku, East Nusa Tenggara (NTT),
9	<i>An. koliensis</i>	Papua, West Papua
10	<i>An. leucosphyrus</i>	Sumatera, Sulawesi, Kalimantan,
11	<i>An. maculatus s.s</i>	Sumatera, West Nusa Tenggara (NTB),
12	<i>An. maculatus s.l.var java</i>	Java
13	<i>An. nigerrimus</i>	Java, Bali, Sumatera, Sulawesi
14	<i>An. parangensis</i>	Sulawesi
15	<i>An. punctulatus</i>	North Maluku, Maluku, Papua, West Papua
16	<i>An. sinensis</i>	Sumatera, Kalimantan,
17	<i>An. subpictus</i>	Java, Bali, Sumatera, Sulawesi, West Nusa Tenggara (NTB), North Maluku, Maluku, East Nusa Tenggara (NTT)
18	<i>An. sundaicus</i>	Java, Bali, Sumatera, West Nusa Tenggara (NTB), East Nusa Tenggara (NTT), Sulawesi
19	<i>An. tessellatus</i>	Sumatera, North Maluku, Maluku
20	<i>An. vagus</i>	Java, Sumatera, West Nusa Tenggara (NTB), East Nusa Tenggara (NTT), Sulawesi

No	<i>Anopheles</i> Species	Location confirmed as malaria vector
21	<i>An. annularis</i>	Java, Bali, Sumatera, Sulawesi
22	<i>An. letifer</i>	Sumatera, Kalimantan
23	<i>An. litoralis</i>	Kalimantan
24	<i>An. ludlowae</i>	Sulawesi, Maluku
25	<i>An. minimus</i>	East Nusa Tenggara (NTT)
26	<i>An. farauti s.l</i>	North Maluku, Maluku, Papua, West Papua
27	<i>An. farauti 4</i>	North Maluku, Papua, West Papua
28	<i>An. oreios</i>	North Maluku
29	<i>An. hinoserum</i>	North Maluku, Papua, West Papua
30	<i>An. epiroticus</i>	Sumatera
31	<i>An. umbrosus</i>	Sumatera, Kalimantan

Based on Table 1, there are 10 *Anopheles* species vector identified in Java and Bali Island were *An. aconitus*, *An. balabacensis*, *An. kochi*, *An. maculatus* s.l (var java), *An. sondaicus*, *An. vagus*, *An. annularis*, *An. nigerrimus*, *An. subpictus*, and *An. flavirostris*. Those species were distributed in various types of ecosystem, from mountains, forest, and also coastal area. Vector infectious diseases are transmitted in specific areas based on geography and the presence of adaptable vectors [17]. A study in Purworejo mentioned the breeding place characteristics, the temperature was 29.8 - 33.9°C, humidity 55-87%, pH 8.1-10.2, and an altitude of 113 - 129 masl [18].

The main malaria vector in Java were *An. balabacensis*, *An. sondaicus* and *An. vagus*. In general mosquitoes found in Central Java sucking blood animal compared to human blood. Species mosquitoes are scattered in the ecosystem forests near and far settlements [19, 20]. The breeding habitat of these species vary from fresh water to brackish water. A number of *Anopheles* spp. mosquito breeding sites were discovered in ponds near rivers and springs [20-27]. There is colleration between breeding habitat with the abiotics factor in the environment A study showed that habitats with *An. farauti* larvae were significantly associated with abiotic (pH, nitrate, ammonia and phosphate concentrations and elevated temperature) and biotic (predators) parameters [28]. A study in Purworejo showed that biting behavior of *An. subpictus* was found from midnight until 02.00 am [24]. Other study showed which because *An. maculatus* takes blood from humans and animals without discrimination, it is known as an indiscriminate biter. Because *An. maculatus* is more usually seen sucking blood outside the home, there is a potential that transmission will occur not just in residential settings, but also in plantations or bushes [23].

Study in West Java showed *An. vagus* is a type of mosquito those who like to bite prefer to be outdoors and biting at dusk until early morning (exophagic), peak at 23.00-24.00 local time. This mosquito is like biting animals (zoophilic) rather than human bite (anthropophilic). The breeding habitat in the form of ponds former ponds that are not well managed, stagnant ditches, presence illegal logging of mangroves is potential habitat for breeding mosquitoes like Brackish water is habitat to *An. sondaicus* and *An. subpictus* larvae, *An. aconitus* and *An. vagus* live in rice fields and abandoned shrimp ponds, and there are many streams sand-covered river (lagoon) which is breeding places for *An. sondaicus* mosquitoes [21].

Sumatera island has more *Anopheles* species identified as malaria vector, that are 14 species, *An. sondaicus*, *An. epiroticus*, *An. vagus*, *An. annularis*, *An. kochi*, *An. maculatus*, *An. sinensis*, *An. letifer*, *An. nigerrimus*, *An. aconitus*, *An. leucosphyrus*, *An. tessellatus*, *An. umbrosus*, and *An. balabacensis*. The habitat of these species are from mountains, forest, and coastal areas. Previous study in South Sumatera showed Most of the *Anopheles* species found sucking the blood of cattle and few suck human blood [19]. Many of the factors important to mosquito development and survival, such as meteorological conditions, vegetation, water body characteristics and land use may be related to topography (mainly landform and

elevation)[29]. Previous study showed that abiotic factor such as temperature, humidity, altitude, topography, influence the distribution of *Anopheles* sp. in Sumatera [30].

A research in Batam reported that *An. sundaicus* bit throughout the night, both indoors and outdoors, with the biting peak occurring between 02.00 am and 03.00 am [31]. The biting behavior of *An. subpictus* was from 23.00 pm to 04.00 am [32, 33]. The *Anopheles sundaicus* mosquito is the main vector that causes malaria in Rajabasa District [32]. Study in Aceh mentioned that *An. kochi* had the maximum blood feed activity during 00:00-01:00 am local time, followed by *An. minimus* and *An. barbiostris* at 01:00-02:00 am. Larvae were found in four types: pond, rain puddles, marshes, and old well. *An. letifer* was discovered in a pond, *An. barbumbrosus* and *An. kochi* in rain puddles, *An. kochi*, *An. aconitus*, *An. vagus*, and *An. separatus* in an abandoned well, and these species are usually found in neglected shrimp ponds, swamps, puddles, and ditches. [34]. A study in South Sumatera The breeding areas discovered were marshes, ditches, ponds, rubber-soaking ponds, bathing pools, puddles of tire ruts, and road puddles [35].

West Nusa Tenggara has six *Anopheles* species that are confirmed as malaria vector, that are *An. sundaicus*, *An. vagus*, *An. subpictus*, *An. balabacensis*, *An. barbiostris*, and *An. maculatus*. A previous study showed *An. vagus* was the main species, with densities peaking between 19.00-20.00 pm, 21.00-22.00 pm, and 01.00 am-02.00 am. Potential *Anopheles* spp breeding sites were discovered near the shore, including lagoons, rivers, and rice paddies [36].

There are more than ten species *Anopheles* confirmed as malaria vector in Sulawesi Island, that are *An. annularis*, *An. barbiostris*, *An. barbumbrosus*, *An. flavirostris*, *An. nigerrimus*, *An. kochi*, *An. parangensis*, *An. leucosphyrus*, *An. ludlowae*, *An. subpictus*, *An. vagus*, and *An. sundaicus*. Those species are distributed in wide range of ecosystems, from mountains, forest to coastal area [19, 37-41]. The main malaria vectors are *An. barbiostris*, *An. parangensis*, *An. ludlowae*, and *An. subpictus*.

Some species were more exophilic than others. *An. barbiostris* and *An. subpictus* are known vectors and suspected vectors of malaria transmission in Central Sulawesi. Both of these probable vector species bit in the same fashion. The peak of biting activity for *An. barbiostris* was near to midnight indoors and outdoors (between 11 pm and 4 am) while for *An. subpictus* was between 9 pm and 3 am, primarily before midnight indoors and outdoors. [38]. *An. ludlowae* in Central Sulawesi sucked blood from both cattle and humans. The maximum population density was MHD 4.42 head/person/hour, which was found in settlement far from non-forest areas. *An. ludlowae* preferred the holes around a river for its breeding habitat [38-42]. A study in Central Sulawesi also showed that the *Anopheles* found tended to be zoophilic, but some of the mosquitoes found were also anthropophilic [19]. The preference of *Anopheles* mosquitoes for feeding on animals (zoophilic) or humans (anthropophilic) can vary depending on several factors, including genetic, ecological, and behavioral elements, species specificity, host availability, genetic factors, host odor, behavioral plasticity, mating behavior, immune response [43, 44].

A study in West Sulawesi showed that mosquito species found and dominant in Tapandullu Village, West Sulawesi is *Anopheles subpictus* and its peak density at 06.00 p.m-07.00 p.m. The breeding habitat found is the lagoon [40]. Other study in Bulukumba, South Sulawesi mentioned that the highest density of mosquitoes is *An. barbiostris* and biting people inside and outside. The behavior of mosquitoes biting people inside the house peaks at 09.00 p.m-10.00 p.m and outside the home the peak occurs at 10.00 p.m-11.00 p.m local time and is predominantly exophagic [37].

There are six species *Anopheles* confirmed as malaria vector in Kalimantan Island, that are *An. leucosphyrus*, *An. letifer*, *An. sinensis*, *An. balabacensis*, *An. litoralis*, and *An. umbrosus*. A study found *Anopheles* spp. use the breeding environment marsh and many limestone puddles as a breeding habitat. *Anopheles* spp. were discovered in Siayuh (Trans)

hamlet, and they are zoophagic and zoophilic, biting and resting outside the house, particularly in cattle [45]. Studies in West Kalimantan show the breeding habitat of *Anopheles* mosquitoes in swamps, rice fields and pond with streams of spring water and rainwater and irrigation. It also mentioned that *Anopheles* in West Kalimantan is zoophilic. The peak of biting activity of *An. barbirostris*, *An. maculatus*, *An. hyrcanus* were found at 09.00 p.m-10.00 p.m, *An. vagus* at 02.00 a.m-03.00 a.m, *An. umbrossus* at 07.00 p.m-08.00 p.m and 10.00 p.m-11.00 p.m [46].

Other study showed the breeding places in North Kalimantan were classified into 8 types, namely dig well, drilled well, Illegal Gold Mining (PETI) well, puddle, fish pond, sewer, swamp, and rice field [47] Abandoned fish ponds are potential breeding habitats and has an important role for the transmission of malaria in Sungai Nyamuk Village, Nunukan, North Kalimantan [48]. As a result, malaria control initiatives must be tailored to the local context in order to be effective [49].

North Maluku has eight *Anopheles* that are confirmed as malaria vector, that are *An. tessellatus*, *An. subpictus*, *An. farauti s.l.*, *An. hinoserum*, *An. farauti 4*, *An. oreios*, *An. punctulatus*, and *An. kochi*. *Anopheles* mosquitoes adapt to their surroundings, from highland environments to coastal settings [50]. Breeding sites of those species in North Maluku discovered included non-permanent/temporary stagnant water, such as on the treads of large vehicles, disused iron plates, and puddles on grass fields that were stagnant with rainwater, as well as damaged mangroves, ponds and springs, as well as slow water [51]. A study in Halmahera demonstrates that zoophagic vectors feed on human and animal hosts while carrying *Plasmodium* parasites, and hence play a major role in transmission [52].

There are six species *Anopheles* confirmed as malaria vector in Maluku. *An. tessellatus*, *An. subpictus*, *An. farauti s.l.*, *An. punctulatus*, *An. kochi*, and *An. ludlowae*. Three species are the main malaria vector, that are *An. tessellatus*, *An. punctulatus* and *An. kochi*. Those species are distributed in many ecosystems from mountains to coastal area. A study showed the average of the *Anopheles* biting activity is at 10.00 p.m-11.00 p.m and the behaviour is exophilic [53]. Other study showed the biting activity of *An. vagus* in Piru Village peaks at 00.00 a.m-01.00 a.m and *An. farauti* at 11.00 p.m-00.00 a.m. *Anopheles* mosquitoes in Piru Village are found resting around the cage at night, the types of larval habitats are rivers, swamps, and puddles. [53, 54].

East Nusa Tenggara is a high endemic area. It has seven *Anopheles* species that are confirmed as malaria vector, *An. vagus*, *An. subpictus*, *An. sundaicus*, *An. minimus*, *An. kochi*, *An. barbirostris*, and *An. flavirostris*. Research states that the breeding habitats for *Anopheles* in West Nusa Tenggara are rivers, puddles, rice fields, lakes, ponds, footprints, buffalo puddles, buffalo footprints and puddles [55, 56]. Those species are distributed in many ecosystems from mountains to coastal areas. A study showed that most *Anopheles* mosquitoes were found in cages at 11.00 p.m-04.00 a.m [56].

Other studies showed the peak of bloodsucking activity inside and outside each other's homes for *An. barbirostris* are at 11:00 p.m–04:00 a.m and 07:00 p.m–04:00 a.m, while *An. subpictus* at 08:00 p.m–09:00 p.m and 10:00 p.m–11:00 p.m [57], *An. sundaicus* at the first peak of activity occurs before midnight and second peak in the morning [57]. Based on the average hourly density, *Anopheles* spp. in East Nusa Tenggara are exophagic and exophilic, that is, they prefer to suck blood outside the home rather than inside home, and prefer to rest outdoors [58, 59]. The host preference of malaria vector *Anopheles* is more likely to be anthropophilic [35].

Papua and West Papua are very high endemic areas, 79% malaria cases are found those two areas. The high endemicity of malaria in Papua and West Papua is caused by several factors including environmental factors, hosts and vectors. The pristine landscape conditions are an ideal breeding place for *Anopheles*. The physical environment, including rainfall, temperature, humidity, altitude, and environmental conditions inside and outside the home

greatly affected the incidence of Malaria in Manokwari, West Papua. Malaria is a serious health problem in Indonesia. The physical condition of the environment is the main factor influencing it [17]. *Anopheles* species that are confirmed as malaria vector are *An. bancrofti*, *An. farauti s.l.*, *An. karwari*, *An. koliensis*, *An. hinoserum*, and *An. punctulatus* group. A study in Biak Numfor and Asmat showed that the biting activity of *An. farauti* mosquito at the coastal and swamp ecosystems lasted all night but mainly at 06:00 p.m to 07:00 p.m [60]. Another study in Jayapura indicated that *An. koliensis* dominated the proportion of *Anopheles* species (96.6% of the species identified), with *An. farauti* having the fewest number by species (0.5%) [61]. Different results from a study in Sarmi Regency, the highest larval habitat is puddles, with the most caught larvae species being *An. maculatus* and *An. longirostris*, and the most caught adult mosquito species being *An. punctulatus* [62].

A study in Papua showed that larva *An. farauti* was identified at brackish water on the shore, natural or constructed ditches. *An. farauti* adults female were nocturnal, exophagic exophilic and anthropophilic. *An. koliensis* were discovered in Sago woodland, semipermanent or permanent shallow sun-exposed pond. This adult mosquitoes were nocturnal, anthropophilic, exophagic, exophilic. The *An. punctulatus* larvae was identified in a pool with clear water, as well as in a sago and swamp forest exposed to direct sunlight. *An. punctulatus* adults were nocturnal, anthropophilic, exophagic, and endophilic [63].

Anopheles spp. discovered in the Tambraw district of West Papua were anthropophilic and endophagic, biting vigorously between 19.00 and 20.00 local time and peaking at 11.00 pm-00.00 am [64]. *An. barbirostris* was observed have biting behavior outside, while some had been known to have bit activity from individuals inside. *An. barbirostris* was discovered breeding in rice fields, ponds, ditches, and rivers [65].

3.2 Malaria elimination in Indonesia

The Republic of Indonesia's Ministry of Health aims to eradicate malaria fully by 2030. The phases to reach this goal are as follows: the last instance of local transmission in 2025, malaria elimination in all provinces in 2028, and elimination in Indonesia in 2030. Malaria elimination will be accomplished in stages by 2030. Malaria elimination occurs at the district/city, provincial, regional, and national levels. Historically, the government has remained on schedule to meet this goal. In 2016, district/city elimination successes were 247, exceeding the year's achievement objective of 245. Meanwhile, in 2017, the government increased malaria elimination successes to 266 districts/cities, up from 265 districts/cities in 2016. This elimination objective grows each year, and it was still met until the pre-pandemic period, notably 285 districts/cities in 2018 and 300 districts/cities in 2019. The government intends to certify 325 districts/cities as malaria-free by 2020, and there will be no high malaria endemic locations in Indonesia [66].

Phase in the elimination of malaria are eradication, pre-elimination, elimination and maintenance phase. The eradication phase aims to reduce the rate of transmission of malaria in a minimal districts/ cities area so that at the end of the phase the slide positivity rate (SPR) <5%. The principal activities undertaken to achieve these objectives are the case finding and management of malaria with laboratory confirmation either microscopically or Rapid Diagnostic Test (RDT), treating all malaria sufferers (positive cases) with effective and safe malaria drugs established by the Ministry of Health (currently using Artemisinin Combination Therapy), Prevention and mitigation of risk factors, among others, by distributing bed nets massively or integrated with other programs, epidemiological surveillance and prevention of outbreaks by improving the ability of public and private health service units (Puskesmas, polyclinics, hospitals) in the implementation of Early Warning System for Outbreak, Malaria outbreaks, increased coverage and quality of records on malaria morbidity and outcomes, conducted mapping of malaria endemic areas from routine

data and survey results, improved communications, information and education (IEC) [67, 68].

Malaria elimination strategies are directed towards efforts achieved national malaria elimination status in 2018 2030 and maintain elimination status (free) malaria. Five principles of intervention were adopted: Ensure universal access to prevention, diagnosis, and treatment malaria, Accelerate achievement malaria free status and maintain free status malaria, Transforming malaria surveillance becomes main intervention, Create an environment in favor of elimination malaria by strengthening health system capacity, mobilization of political commitment, community mobilization and increased support partnership, and Improve service by using innovation and research[3].

3.3 Challenges in malaria elimination

Malaria elimination presents considerable obstacles in both endemic and non-endemic areas of Indonesia. Despite significant success in reducing the malaria load, the country still confronts a number of challenges to achieving long-term elimination. Indonesia's vast geographical diversity, comprising thousands of islands with diverse ecosystems and climates, presents challenges for malaria control and elimination efforts. Remote and isolated regions, especially in eastern Indonesia, often lack adequate healthcare infrastructure, making it difficult to reach populations at risk and deliver essential malaria control interventions. Many species of *Anopheles* mosquito were distributed in Indonesia, some of which are highly efficient vectors of malaria parasites. These vectors exhibit diverse breeding habits, biting behaviors, and responses to control measures. Additionally, the emergence of insecticide resistance in *Anopheles* mosquitoes complicates vector control efforts, reducing the effectiveness of conventional insecticide-based interventions such as indoor residual spraying and bed nets. Population movements, including migration, travel, and seasonal labor movements, contribute to the spread of malaria within and across regions. Mobile and migrant populations often reside in remote or underserved areas with limited access to healthcare services, increasing their vulnerability to malaria infection and hindering surveillance and response efforts [3].

3.4 Malaria vector control

Controlling malaria vectors, especially complex species like those of the *Anopheles* genus, in Indonesia needs a multimodal approach due to the country's diverse terrain, varying vector behavior, and limitations in healthcare infrastructure. Surveillance and monitoring of mosquito populations is critical for understanding the range, abundance, and behavior of malaria vectors, particularly *Anopheles* complex. This knowledge is useful when creating focused control interventions. Larval surveys, adult trapping, and molecular analysis can all help identify vector species and monitor insecticide resistance. Implementing integrated vector management approaches that include numerous control measures customized to local conditions can improve the efficacy and durability of vector control initiatives. IVM stresses evidence-based decision-making, community engagement, and cross-sector collaboration [13].

Given Indonesia's numerous biological environments, vector control requires careful environmental management. This entails changing or eliminating vector breeding habitats, such as stagnant water bodies, by improving drainage, filling ditches, or applying larvicides. Furthermore, community participation in environmental cleanup programs might help minimize vector breeding environments. Continued investment in research and innovation is critical for creating novel vector control techniques, monitoring pesticide resistance, and better understanding the ecological and behavioral aspects of malaria vectors in Indonesia.

Collaborative research efforts with local and international partners can help to design and implement effective control techniques [13].

There are three vector control principles that aim to break the chain of malaria transmission. These three principles are to decrease the vectors density, reducing the survival and longevity of vectors, and reduce human and vector contact. Some control activities to reduce vector density are environmental management (hoarding and cleaning of mosquito breeding areas), use of larvicides, use of biological controls, and spraying of space insecticides (thermal fogging, ultra low volume / ULV insecticides). Two activities are aimed to reduce the survival and longevity of vectors, that are Indoor residual spraying and using the Long Lasting Insecticide Nets (LLIN). Several activities can be conducted to avoid human contact with malaria vector, using LLIN, house screening, repellent, and also using the household insecticide products (coils, mats, aerosol, dispenser, etc) [13].

One of the malaria vector control programs in Indonesia is by distributing insecticide-treated nets (Long Lasting Insecticide Nets/LLIN). This insecticide-treated mosquito net is expected to protect people from mosquito bites at night. This mosquito net can last up to three years and can be washed 30 times [68]. Distribution of mosquito nets is prioritized for ages at risk of contracting malaria, namely toddlers and pregnant women. The purpose of this application for ages at risk is to protect pregnant women and their babies from malaria transmission and encourage an increase in the coverage of routine services for pregnant women and to reduce stunting rates due to anemia in pregnant women and infants infected with malaria [69].

Control efforts were expanded to distant and poorly populated eastern Indonesian areas where transmission was strong and vectors were more effective. Subnational campaigns introduced long-lasting insecticide-treated bednets to eastern Indonesia and parts of Sumatra in 2005, to all of Sumatra in 2007, to Kalimantan and Sulawesi in 2009, and to highly endemic districts and villages nearly every two years after that, where continuous distribution was integrated with routine immunization and antenatal care services (with malaria screening during pregnancy). During the last decade, 20 million insecticide-treated bednets have been supplied. Indoor residual spraying was used in high-risk villages (annual parasite incidence greater than 20 per 1000 people) and as a response to epidemics [70].

Various studies have identified and known various biological agents that can act as vector biological controllers. The combination of carp (*Cyprinus carpio*) and *P. reticulata* can control *An aconitus* by 99.7% with a fish density of 2 fish/m². While the use of Tilapia in Cilacap can control the malaria vector *An. sundaicus*. Copepod *Mesocyclops* is also a biological agent that can be used to control immature stages of vectors [71].

4 Conclusions

In Indonesia, 31 *Anopheles* mosquito species have been identified as malaria vectors. Vector control and entomological surveillance of malaria are one of the main domains for achieving malaria elimination. Therefore, a combination of national policies, local-specific, habitat-specific, and community participation approaches are needed for effective malaria vector control in Indonesia.

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