Jurnal Epidemiologi Kesehatan Komunitas
10 (4), 2025, 14-24

JEKK

Identification of Malaria Receptive Areas to Support Elimination Maintenance in Gunungkidul District, Indonesia, 2023

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Article Information : Received 17 April 2025 ; Last Revised 25 October 2025 ; Accepted 30 October 2025 ; Available Online 7 November 2025 ; Published 7 November 2025

ABSTRACT

Background: The Gunungkidul District in Indonesia achieved malaria elimination status in 2014; however, the risk of reintroduction remains due to environmental suitability and population mobility. This study aimed to identify malaria-receptive areas in Gunungkidul District through spatial and environmental analyses to support the strategic maintenance of malaria elimination.
Methods: A descriptive observational study was conducted using secondary data from a vector survey conducted in October 2023 across 18 sub-districts. Geographic Information System (GIS) mapping and larval habitat index (LHI) calculations were used to identify potential Anopheles breeding sites. Climate data from 2020 to 2023 were analyzed to assess environmental receptivity.
Result: Rivers were the most common breeding sites for *Anopheles* mosquitoes (59.41%), followed by lakes and springs. Gedangsari and Karangmojo sub-districts showed the highest larval habitat indices, indicating localized malaria receptivity in these areas. Climatic factors, such as high rainfall and humidity during the wet season, support year-round mosquito breeding. In 2023, four imported malaria cases were reported, underscoring the district's continued vulnerability.
Conclusion : Spatial identification of malaria-receptive areas provides operational evidence to support the maintenance of the elimination status in the Gunungkidul District. Targeted surveillance and vector control in high-risk sub-districts, along with a rapid response to imported cases, are essential to prevent malaria re-establishment.

Keywords: elimination status maintenance; malaria-receptive areas; vector survey

DOI : https://doi.org/10.14710/jekk.v10i4.28333

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Introduction

Malaria continues to pose a significant global health challenge, despite considerable progress in controlling and eliminating the disease over the past several decades.[1,2] It remains one of the most prevalent vector-borne diseases, responsible for an estimated 249 million cases and 608,000 deaths worldwide in 2020 alone. This enduring burden, particularly in sub-Saharan Africa and parts of Asia, underscores the importance of continued vigilance and strategic efforts to eradicate malaria globally.[3] The World Health Organization (WHO) Introduced the Global Technical Strategy for Malaria 2016–2030, setting a target to reduce malaria incidence and mortality by at least 90% relative to 2015 levels. This ambitious plan focuses on both eliminating malaria transmission in more than 35 countries and preventing re-infection in nations that have already achieved malaria-free status.[4] By combining strengthened surveillance, targeted interventions, and continuous monitoring, the strategy aims to sustain long-term progress against malaria while addressing potential challenges in maintaining disease-free conditions. Achieving these objectives is also critical for advancing the broader health-related targets within the Sustainable Development Goals (SDGs), particularly SDG 3, which seeks to promote well-being and ensure healthy lives for all.[5]

The roadmap proposed by the WHO is crucial not only for malaria control but also for enhancing the capacity of national and regional health systems. Within this global framework, WHO launched the E-2020 and E-2025 initiatives, which acknowledge countries approaching malaria elimination by 2020 and 2025, respectively.[6] These programs highlight the need for context-specific strategies to address malaria in endemic areas while fostering international cooperation.[5,7] Nevertheless, malaria transmission continues in certain regions, particularly those characterized by high population mobility and insufficient vector control measures.[8]

In Southeast Asia, Indonesia is among the countries contributing most significantly to the regional malaria burden, reporting over 1.16 million cases in 2020 and ranking as the second most malaria-endemic country after India.[3] According to data from the Ministry of Health, malaria cases in Indonesia rose from 254,055 in 2020 to 443,530 in 2022. This increase in cases has been accompanied by a rise in mortality, with 71 deaths reported in 2022, representing the highest number recorded over the past five years.[9] These figures underscore the persistent challenges Indonesia faces in achieving sustained malaria control and eventual elimination. The Indonesian government has responded with renewed efforts to accelerate the elimination of malaria by 2030, as articulated in the Minister of Health Regulation Number 22 of 2022, concerning Malaria Management.[10] As of 2021, 347 districts representing 67.5% of Indonesia’s total districts have achieved malaria elimination, underscoring significant progress.[9] Gunungkidul District, located in the Special Region of Yogyakarta, received its Malaria Elimination Certificate in 2014, positioning it as a leader in malaria control efforts in the region.[11]

However, achieving and maintaining malaria elimination is a dynamic challenge, particularly for districts like Gunungkidul District that have already reached the elimination stage.[12] Malaria prevention strategies follow a structured approach that includes the acceleration, intensification, elimination, and maintenance phases, each tailored to the endemicity level of the region.[13] Although the elimination of indigenous malaria cases may be attained, the threat of re-infection persists, largely driven by the potential importation of cases from endemic regions.[14] This risk is particularly pronounced in areas with high population mobility, where frequent travel between locations with differing malaria transmission intensities can facilitate the continued spread of the disease.[15]

Environmental factors, including temperature, humidity, and rainfall, continue to play a crucial role in the breeding and survival of *Anopheles* mosquitoes, the primary vectors of malaria transmission.[16] The presence of favorable mosquito habitats in areas such as Gunungkidul District, which is characterized by variable rainfall and temperature patterns, highlights the need to consider environmental determinants in malaria control strategies.[16] Additionally, climate change and seasonal weather fluctuations can further complicate control efforts, posing new challenges to sustaining malaria elimination.[17,18]

In Gunungkidul District, tourism plays a significant role in both the region's economy and its malaria control strategy.[19] In 2022, the Gunungkidul District Tourism Office recorded 3,106,772 visitors, reflecting the area's strong appeal as a tourist destination.[20] Nevertheless, the arrival of travelers, particularly from malaria-endemic regions, elevates the risk of imported malaria cases.[14,15] In 2023, four such imported cases were reported, indicating that Gunungkidul District remains susceptible despite having achieved elimination status.[21] This situation underscores the importance of ongoing surveillance and vector control, particularly in locations frequently visited by tourists.[8,15]

Despite progress in malaria elimination, few studies systematically map malaria-receptive areas in districts that have achieved elimination. Most research in Indonesia has focused on endemic regions to reduce incidence, while strategies for sustaining elimination remain underexplored. Moreover, district-level evidence integrating entomological data with spatial environmental analyses to guide risk-based surveillance is scarce.

Therefore, maintaining malaria elimination status in Gunungkidul District requires a comprehensive and sustainable approach that integrates strengthened surveillance systems, targeted vector control, and localized risk mapping. Particular attention is needed to identify malaria-receptive areas where environmental and epidemiological conditions may allow re-establishment of transmission, especially in zones with high human mobility and tourist activity.[8,14,22] This study aimed to identify malaria-receptive areas in Gunungkidul District by assessing the presence of Anopheles larvae and analyzing spatial environmental conditions that support mosquito breeding. The results are expected to support the strategic maintenance of malaria elimination by providing geographically targeted evidence for intervention planning, resource allocation and risk-based surveillance.

Methods

This study employed a descriptive observational design with a *cross-sectional* approach. Secondary data from a vector survey conducted by the Yogyakarta Special Region Provincial Health Office in October 2023 were used. The survey covered 18 sub-districts within the Gunungkidul District and provided detailed information on mosquito vector populations and their potential breeding sites.

Geographic Information System (GIS) software, specifically ArcGIS version 10.8, was used to create spatial visualizations of malaria-receptive areas. The spatial analysis involved overlaying larval breeding site locations, the larval habitat index (LHI), and sub-district administrative boundaries. These spatial variables were obtained directly from vector surveys. Environmental variables, including the types of water bodies and the geographic coordinates of each breeding site, were geocoded and spatially analyzed to identify zones with increased receptivity to malaria transmission.

In addition to mapping the receptive areas, the larval habitat index was calculated to assess the proportion of surveyed sites that tested positive for Anopheles mosquito larvae. These indices were compared with environmental health standards for vector-borne diseases to evaluate the relative risk of malaria re-establishment across sub-districts.

To strengthen the interpretation, climate data from 2020 to 2023, including average temperature, relative humidity, rainfall, and number of rainy days, were obtained from the National Central Bureau of Statistics. These climatic parameters were analysed descriptively and compared with the distribution of larval habitats to contextualize whether the environmental conditions in recent years supported *Anopheles* receptivity.

The combined spatial, environmental, and climatic analyses aimed to identify and prioritize malaria-receptive areas, thereby supporting targeted interventions to maintain the malaria elimination status of the Gunungkidul District.

Result

In 2023, vector surveys were conducted across the Gunungkidul District to identify potential breeding sites for *Anopheles* mosquitoes, which are key to maintaining the malaria elimination status of the region. A total of 1,700 potential mosquito breeding sites across 18 sub-districts were inspected in the study. The findings revealed several prominent breeding habitats for *Anopheles* larvae.

Table 1. Distribution of Anopheles spp. Mosquitoes Breeding Sites in Gunungkidul District

Types of Breeding Places	Total (N=1,700) n (%)
Reservoir	26 (1.53)
Used Pond	9 (0.53)
Waterhole	50 (2.94)
Spring	123 (7.24)
Wood Soakage	2 (0.12)
Irrigation Canal	41 (2.41)
Rice Field	102 (6.00)
Well	20 (1.18)
River	1,010 (59.41)
Reservoir	317 (18.65)

Table 2. Distribution of Positive Breeding Places of Anopheles Mosquitoes

Types of Breeding Places	Total (N=7) n (%)
River	4 (57.14)
Waterhole	2 (28.57)
Irrigation Canal	1 (14.29)

Among the 1,700 breeding sites surveyed, the highest proportion of positive breeding habitats for *Anopheles* mosquito larvae was found in rivers, which accounted for 57.14% of the positive sites (Table 2). Waterholes and irrigation canals accounted for 28.57% and 14.29%, respectively. These results suggest that, although rivers are the most frequent breeding sites, they also harbor the highest proportion of positive mosquito larvae, indicating a higher risk of malaria transmission in areas near rivers.

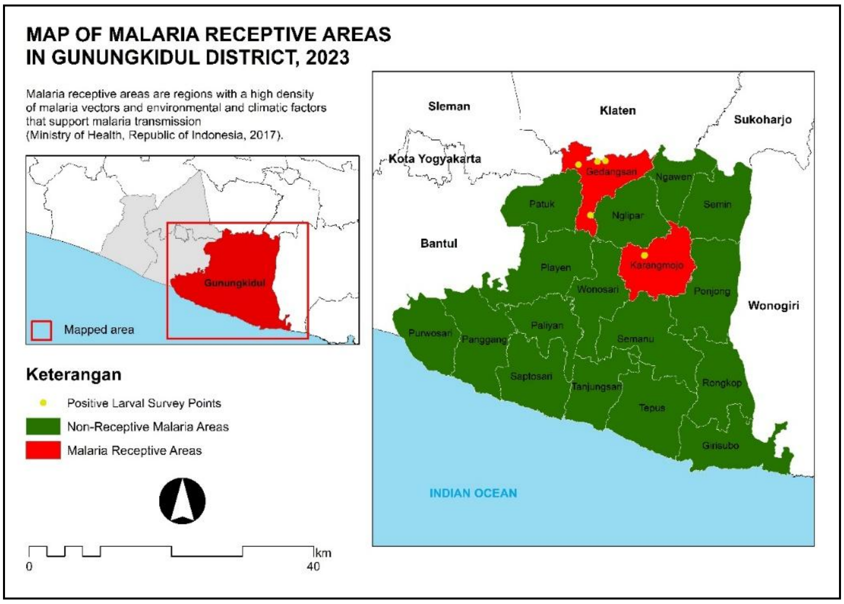

Figure 1. Map of Malaria Receptive Areas in Gunungkidul District, Indonesia, 2023

Table 3. Habitat Index of Anopheles spp. Larvae in Sub – districts with Positive Breeding Sites

Sub-district	Observed Sites (n)	Positive Sites (n)	Habitat Index (%)
Gedangsari	75	4	5.33
Karangmojo	100	3	3.00

As illustrated in Figure 1, the map of malaria-receptive areas in Gunungkidul District reveals that Gedangsari and Karangmojo sub-districts are the most malaria-receptive, with positive *Anopheles* larvae found in 5.33% of breeding sites in Gedangsari and 3.00% in Karangmojo sub-districts (Table 3). These findings highlight the need for intensified surveillance and control measures in these sub-districts to prevent malaria transmissions. In contrast, other sub-districts, such as Girisubo, Ngawen, and Nglipar, showed no positive larvae presence, indicating a lower risk of malaria in these areas during the study period.

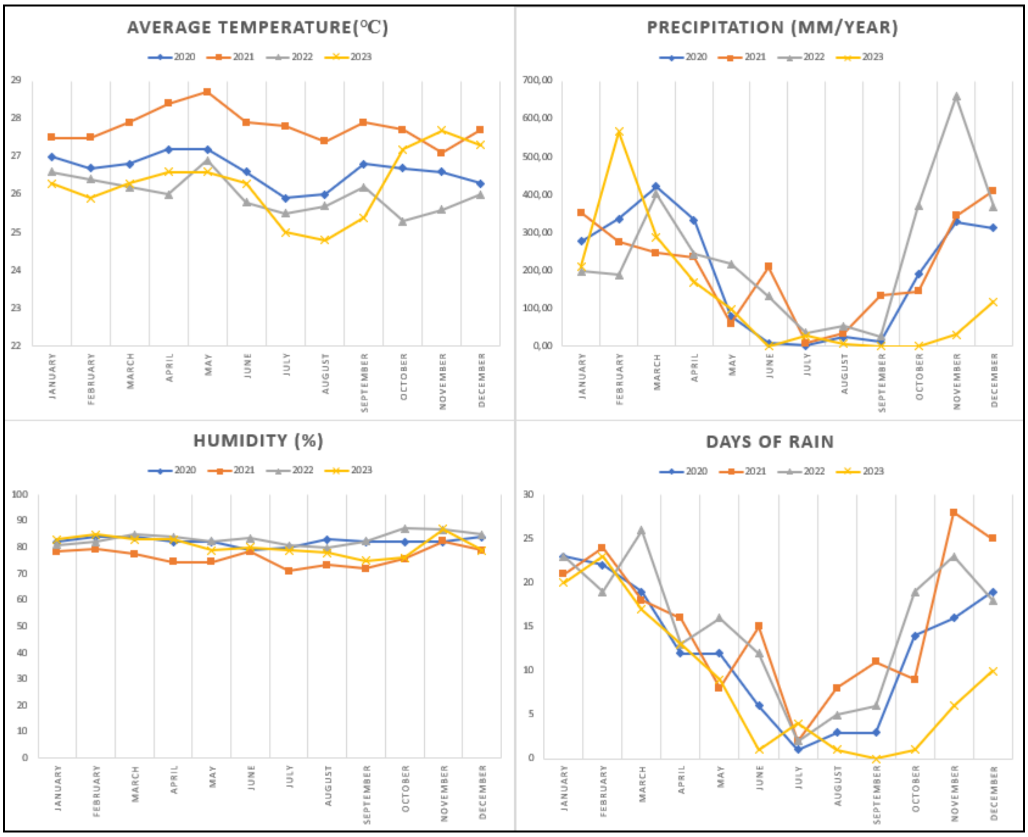

Figure 2. Climate parameter in Gunungkidul District between 2020 – 2023

Based on the graph in Figure 2, the climate parameters for Gunungkidul District between 2020 and 2023 showed distinct inter-annual variations in temperature, precipitation, humidity, and rainy days. In general, average temperatures tended to rise during the dry season months. However, an anomaly was observed in 2021, when the highest average temperature occurred in May rather than in July or August. The lowest temperatures across the four years were recorded in 2023, particularly between June and August. Precipitation patterns reflected clear wet and dry season cycles. Over the past four years, 2023 recorded the lowest annual rainfall, with very limited precipitation between June and October. This contrasts with 2022, when rainfall increased again in October despite preceding dry months. Relative humidity remained stable throughout most months but consistently increased toward the end of each year. In 2021, humidity rose steadily from September to December. This seasonal increase in humidity aligned with a rise in both the number of rainy days and the intensity of rainfall. The number of rainy days peaked in the wet season for all years, but the highest overall frequency occurred in 2021. In contrast, 2020 recorded fewer rainy days, particularly in the mid-year months.

Discussion

This study provides valuable insights into the environmental and climatic factors influencing malaria receptivity in Gunungkidul District, with the goal of supporting long-term elimination maintenance. By identifying sub-districts with high receptivity and linking them with ecological and climatic data, this study provides operational evidence to guide risk-based vector control and surveillance. These results emphasize the importance of water bodies, particularly rivers, as major breeding sites for *Anopheles* mosquitoes. Rivers, owing to their varying flow rates and abundant vegetation along the riverbanks, create optimal conditions for mosquito larval development. This finding aligns with prior studies that have demonstrated that rivers offer stable and protected habitats for mosquito breeding, where larvae are shielded from physical disturbances and the water remains conducive to their growth.[23–26] The presence of positive larvae in rivers underlines their central role in sustaining mosquito populations, making riverbank areas a critical focus for vector control interventions.

Although lakes and springs also serve as breeding sites, their contribution is secondary to that of rivers. Lakes, especially those with slow-moving or stagnant water, provide stable conditions for mosquito larvae, whereas springs offer clean and nutrient-rich water, both of which foster larval survival. The ability of these water bodies to maintain relatively calm water conditions allows for better temperature regulation and water quality, which are essential for the development of mosquitoes. As noted in previous studies, clear water and minimal physical disturbances support the growth of algae and microorganisms, which are vital for larval nutrition.[27] This study’s findings are consistent with existing literature that emphasizes the importance of these environments in creating optimal conditions for *Anopheles* larvae, particularly rivers and lakes.[28,29]

One of the key results of this study was the identification of sub-districts with high habitat indices, such as Gedangsari and Karangmojo, which indicate areas of heightened malaria transmission risk. The presence of positive larvae in these areas signals favorable conditions for *Anopheles* mosquitoes, presenting a higher likelihood of malaria reintroduction, especially when coupled with imported cases from endemic regions.[30–32] The importance of these sub-districts cannot be overstated, as they demonstrate that even in regions with declared malaria elimination status, the persistence of favorable breeding conditions poses a significant risk for transmission.[30,31,33] These areas must be closely monitored to prevent malaria outbreaks that could threaten ongoing malaria control efforts in the country.

Climatic factors, including temperature, humidity, and precipitation, are key determinants of the life cycle and breeding places of *Anopheles* mosquitoes.[16–18] The temperature patterns observed over the past four years in Gunungkidul District revealed a consistent annual fluctuation, with temperatures rising from March to May, peaking in May, and decreasing in August, before rising again. In 2021, temperatures reached their highest levels, with peak months recording particularly intense heat, while 2023 was comparatively cooler. *Anopheles* mosquitoes develop optimally within temperatures ranging from 25°C to 36°C, which aligns closely with the conditions observed in Gunungkidul District throughout the year.[34,35] This favorable temperature range allows uninterrupted completion of their life cycle, supporting continuous growth and reproduction.[16,34,35] Coupled with consistently suitable breeding habitats, these stable environmental conditions make Gunungkidul District highly conducive to *Anopheles* mosquito survival, sustaining their population year-round.

Humidity levels in Gunungkidul District, ranging from 70% to 90%, play a key role in supporting the survival and reproduction of *Anopheles* mosquitoes. Studies indicate that while mosquitoes are adversely affected by very low humidity below 10%, they thrive in conditions with 60%–100% humidity, which is optimal for their life cycle.[36] Combined with favorable temperature conditions, the district's relatively stable humidity creates an environment conducive to continuous mosquito development and proliferation.[37] These observations underscore the importance of consistent environmental conditions in sustaining mosquito breeding and survival throughout the year.

The precipitation patterns in Gunungkidul District, characterized by heavy rainfall during the wet season from September to December, further enhance the availability of mosquito breeding sites. Extended periods of high rainfall lead to the accumulation of standing water in natural reservoirs, creating optimal conditions for the development of mosquito larvae and increasing the overall risk of vector proliferation.[38] The high rainfall in 2023, particularly in the final quarter, created favorable breeding conditions for mosquitoes, even in the early stages of the rainy season. This observation aligns with previous studies that have shown how intense rainfall during the wet season significantly increases the number of mosquito breeding sites and consequently the risk of malaria transmission.[16,37,38] The presence of prolonged rainy days exacerbates this, with the number of rainy days in 2023 peaking, facilitating the continuous presence of standing water.

Population mobility, especially that of tourists, also plays a critical role in the malaria transmission dynamics in Gunungkidul District. The influx of tourists from malaria-endemic areas contributes to the risk of malaria reintroduction.[14,19] Previous studies have similarly highlighted that human mobility is a major driver of imported malaria and can undermine elimination efforts. For instance, in Zambia, GPS tracking showed that people spent around 10.6% of their time away from households, with seasonal increases in long-distance movement, highlighting the potential for parasite importation.[39] In Brazil, analysis of imported malaria cases from 2004–2022 demonstrated that between-state movement has become proportionally more important than within-state movement, with persistent source clusters and seasonal importation patterns impeding subnational elimination.[40] Cross-border mobility in Bhutan represents a key factor in the importation of malaria, particularly as the nation approaches elimination.[41]

Although the district has achieved substantial reductions in local malaria transmission, the occurrence of imported cases emphasizes the persistent risk associated with population mobility. This situation highlights the necessity for robust surveillance systems to monitor high-risk travelers and migrants who may reintroduce the parasite into the area.[21] The reported imported malaria cases in 2023 demonstrate that, despite considerable progress in control efforts, the threat of parasite importation continues to pose a significant challenge to sustaining elimination status.

To address these risks and enhance malaria control efforts, Gunungkidul District should prioritize the monitoring and management of mosquito breeding sites. Considering the significant contribution of rivers, lakes, and springs to mosquito populations, it is essential to implement targeted vector control measures, including larval management, environmental modification, and the use of insecticide-treated nets, within malaria control programs.[5,30] Moreover, engaging the community and conducting public education campaigns are critical for raising awareness about the importance of eliminating mosquito breeding habitats, particularly during the rainy season. Active local participation in monitoring and controlling breeding sites can substantially improve the overall effectiveness of malaria control strategies.[42]

Improving the rapid identification and management of imported malaria cases is imperative. Systematic registration and oversight of travelers and migrants from endemic areas are vital to prevent reintroduction of the parasite.[43,44] An early warning system that integrates mobility data, surveillance reports, and climatic conditions will further strengthen the district's capacity to anticipate and respond to risks of malaria importation.[45] Continuous research and localized monitoring are also essential to ensure adaptive elimination strategies. Finally, strengthening cross-sectoral collaboration (PPM) between government agencies, tourism and transportation authorities, and private stakeholders will support coordinated prevention, rapid response, and sustainable resource allocation.[46]

This study had several limitations. First, it relied solely on secondary data from a single vector survey conducted in October 2023, which may not capture seasonal variations in mosquito breeding activity throughout the year. Second, data were unavailable for two sub-districts, Panggang and Tanjungsari; therefore, malaria receptivity in those areas could not be assessed. Third, the study focused primarily on entomological and environmental parameters without integrating socio-behavioral or health service access factors that could also influence the risk of malaria reintroduction. Future studies should consider longitudinal data and incorporate broader determinants of malaria transmission. Despite these limitations, this study provides an important preliminary framework for spatially guided malaria elimination maintenance in receptive regions.

Conclusions

This study identified rivers as the primary breeding sites for *Anopheles* mosquitoes in the Gunungkidul District, with lakes and springs also contributing to receptivity. Climatic conditions, particularly high rainfall, temperature, and humidity, create favorable environments for mosquito breeding, especially during the wet season. The identification of high-risk sub-districts, such as Gedangsari and Karangmojo, highlights the spatial heterogeneity of malaria receptivity within the district. These findings provide critical input to support the maintenance of malaria elimination status in Gunungkidul by enabling risk-based prioritization of surveillance and vector control measures. Strengthening the early detection of imported cases, conducting targeted vector interventions, and sustaining community engagement are essential to prevent the re-establishment of local transmission in receptive areas.

Acknowledgement

We acknowledge the Yogyakarta Special Region Provincial Health Office for providing data from the vector study conducted in Gunungkidul District, the National Central Bureau of Statistics for providing climate parameter data in Gunungkidul District between 2020 and 2023, and the Gunungkidul District Health Office for granting permission to conduct this research.

References

1. Chalapareddy SK, Sajid A, Saxena M, Arora K, Guha R, Arora G. Emerging therapeutic modalities against malaria. In: Translational Biotechnology. Elsevier; 2021. p. 267–86.
2. Ansah EK, Moucheraud C, Arogundade L, Rangel GW. Rethinking integrated service delivery for malaria. Fatokun O, editor. PLOS Glob Public Heal. 2022 Jun;2(6):e0000462.
3. World Health Organization. World malaria report 2023. Geneva; 2023.
4. World Health Organization. Global Malaria Programme operational strategy 2024-2030. Geneva; 2024. 1–84 p.

5. Thellier M, Gemegah AAJ, Tantaoui I. Global Fight against Malaria: Goals and Achievements 1900–2022. J Clin Med. 2024 Sep;13(19):5680.
6. Mwenesi H, Mbogo C, Casamitjana N, Castro MC, Itoe MA, Okonofua F, et al. Rethinking human resources and capacity building needs for malaria control and elimination in Africa. Lindtjorn B, editor. PLOS Glob Public Heal. 2022 May;2(5):e0000210.
7. Wang ZB, Xie Z, Yan SR, Cao J. Main non-state actors and progress of actions in global malaria elimination programme: A review. Chinese J Schistosomiasis Control. 2020;32(4):436–40.
8. Hemingway J. Vectors: recognising the challenge and reducing neglect. Int Health. 2019 Sep;11(5):341–3.
9. Ministry of Health Indonesia. Annual Report 2022 Malaria. Directorate General for Disease Prevention and Control. Ministry of Health RI. 2023.
10. Kementerian Kesehatan Republik Indonesia. Peraturan Menteri Kesehatan Republik Indonesia Nomor 22 Tahun 2022 Tentang penanggulangan Malaria. Indonesia: JDIH BPK; 2022 p. 1–103.
11. Mulyawati A, Sukesi TW, Mulasari SA, Setiawan YD, Yuliani Y, Patmasari Y, et al. Analisis Situasi Luas Wilayah Reseptif Malaria di Kabupaten Gunungkidul Daerah Istimewa Yogyakarta Tahun 2021. Sanitasi J Kesehat Lingkung. 2022;15(1):47–60.
12. Tsoka-Gwegweni JM. Status of malaria and its implications for elimination in an endemic province of South Africa: retrospective analysis. Pan Afr Med J. 2022;41.
13. Mao W, Cooke R, Silimperi D, Urli Hodges E, Ortiz E, Udayakumar K. Scaling malaria interventions: bottlenecks to malaria elimination. BMJ Glob Heal. 2023 Nov;8(11):e013378.
14. Huang F, Feng XY, Zhou SS, Tang LH, Xia ZG. Establishing and applying an adaptive strategy and approach to eliminating malaria: practice and lessons learnt from China from 2011 to 2020. Emerg Microbes Infect. 2022 Dec;11(1):314–25.
15. Lalloo DG, Magill AJ. Malaria. In: Travel Medicine. Elsevier; 2019. p. 137–44.
16. Le PV V., Kumar P, Ruiz MO, Mbogo C, Muturi EJ. Predicting the direct and indirect impacts of climate change on malaria in coastal Kenya. Keller DP, editor. PLoS One. 2019 Feb;14(2):e0211258.
17. Ryan SJ, Lippi CA, Zermoglio F. Shifting transmission risk for malaria in Africa with climate change: a framework for planning and intervention. Malar J. 2020 May;19(1):170.
18. Rubuga FK, Ahmed A, Siddig E, Sera F, Moirano G, Aimable M, et al. Potential impact of climatic factors on malaria in Rwanda between 2012 and 2021: a time-series analysis. Malar J. 2024 Sep;23(1):274.
19. Zhao L, Zhou G, Li C. Research on the impact of tourism cooperation on urban public health. Front Public Heal. 2025 Mar;13.
20. Badan Pusat Statistik. Kabupaten Gunungkidul Dalam Angka. Gunungkidul; 2022.
21. Lourenço C, Tatem AJ, Atkinson PM, Cohen JM, Pindolia D, Bhavnani D, et al. Strengthening surveillance systems for malaria elimination: a global landscaping of system performance, 2015–2017. Malar J. 2019 Dec;18(1):315.
22. Ranathunge RMTB, Kannangara D, Gunatilaka PADHN, Abeyewickreme W, Hapugoda M. Occurrence of major and potential malaria vector immature stages in different breeding habitats and associated biotic and abiotic characters in the district of Trincomalee Sri Lanka. J Vector Borne Dis. 2020;57(1):85.
23. Nikookar SH, Fazeli-Dinan M, Azari-Hamidian S, Mousavinasab SN, Aarabi M, Ziapour SP, et al. Correlation between mosquito larval density and their habitat physicochemical characteristics in Mazandaran Province,

northern Iran. Apperson C, editor. PLoS Negl Trop Dis. 2017 Aug;11(8):e0005835.
24. Multini LC, Oliveira-Christe R, Medeiros-Sousa AR, Evangelista E, Barrio-Nuevo KM, Mucci LF, et al. The Influence of the pH and Salinity of Water in Breeding Sites on the Occurrence and Community Composition of Immature Mosquitoes in the Green Belt of the City of São Paulo, Brazil. Insects. 2021 Sep;12(9):797.
25. Duchet C, Mukherjee S, Stein M, Spencer M, Blaustein L. Effect of desiccation on mosquito oviposition site selection in Mediterranean temporary habitats. Ecol Entomol. 2020 Jun;45(3):498–513.
26. Poerwanto SH, Ahmad S, Giyantolin, Windyaraini DH. Characterization of mosquitoes breeding site (Diptera: Culicidae) in Bogowonto Lagoon ecosystem, Kulonprogo districts, special region of Yogyakarta, Indonesia. In 2020. p. 040026.
27. Linenberg I, Christophides GK, Gendrin M. Larval diet affects mosquito development and permissiveness to Plasmodium infection. Sci Rep. 2016 Dec;6(1):38230.
28. Getachew D, Balkew M, Tekie H. Anopheles larval species composition and characterization of breeding habitats in two localities in the Ghibe River Basin, southwestern Ethiopia. Malar J. 2020 Dec;19(1):65.
29. dos Reis IC, Codeço CT, Degener CM, Keppeler EC, Muniz MM, de Oliveira FGS, et al. Contribution of fish farming ponds to the production of immature Anopheles spp. in a malaria-endemic Amazonian town. Malar J. 2015 Dec;14(1):452.
30. Brooke BD. Malaria Vector Surveillance and Control in an Elimination Setting in South Africa. Trop Med Infect Dis. 2022 Nov;7(11):391.
31. Abossie A, Demissew A, Getachew H, Tsegaye A, Degefa T, Habtamu K, et al. Higher outdoor mosquito density and Plasmodium infection rates in and around malaria index case households in low transmission settings of Ethiopia: Implications for vector control. Parasit Vectors. 2024 Feb;17(1):53.
32. Djègbè NDC, Da DF, Somé BM, Paré LIG, Cissé F, Mamai W, et al. Anopheles aquatic development kinetic and adults' longevity through different seasons in laboratory and semi-field conditions in Burkina Faso. Parasit Vectors. 2024 Apr;17(1):181.
33. Belay AK, Asale A, Sole CL, Yusuf AA, Torto B, Mutero CM, et al. Feeding habits and malaria parasite infection of Anopheles mosquitoes in selected agroecological areas of Northwestern Ethiopia. Parasit Vectors. 2024 Oct;17(1):412.
34. Agyekum TP, Arko-Mensah J, Botwe PK, Hogarh JN, Issah I, Dwomoh D, et al. Effects of elevated temperatures on the development of immature stages of Anopheles gambiae (s.l.) mosquitoes. Trop Med Int Heal. 2022 Apr;27(4):338–46.
35. Murdock CC, Sternberg ED, Thomas MB. Malaria transmission potential could be reduced with current and future climate change. Sci Rep. 2016 Jun;6(1):27771.
36. Leite LN, Bascuñán P, Dotson EM, Benedict MQ. Anopheles Adult Anesthesia, Feeding, and Sex Separation. Cold Spring Harb Protoc. 2024 Mar;2024(3):pdb.prot108188.
37. Prasad P, Gupta SK, Mahto KK, Kumar G, Rani A, Velan I, et al. Influence of climatic factors on the life stages of Aedes mosquitoes and vectorial transmission: A review. J Vector Borne Dis. 2024 Apr;61(2):158–66.
38. Kodindo ID, Saleh IDM, Betrand FN, Boulotigam K, Mahamat HM, Belemel FD, et al. Impact des inondations induites par le changement climatique sur la transmission du paludisme à N'Djaména. Int J Biol Chem Sci. 2025 Jan;18(5):1683–90.
39. Searle KM, Lubinda J, Hamapumbu H, Shields TM, Curriero FC, Smith DL, et al. Characterizing and quantifying

human movement patterns using GPS data loggers in an area approaching malaria elimination in rural southern Zambia. R Soc Open Sci [Internet]. 2017 May 3;4(5):170046. Available from: https://royalsocietypublishing.org/doi/10.1098/rsos.170046

40. Arisco NJ, Peterka C, Castro MC. Spatiotemporal analysis of within-country imported malaria in Brazilian municipalities, 2004–2022. Mutheneni SR, editor. PLOS Glob Public Heal [Internet]. 2024 Jul 15;4(7):e0003452. Available from: https://dx.plos.org/10.1371/journal.pgph.0003452
41. Penjor K, Zangpo U, Tshering D, Ley B, Price RN, Wangdi K. Imported malaria and its implication to achievement of malaria-free Bhutan. J Travel Med [Internet]. 2023 May 18;30(3). Available from: https://academic.oup.com/jtm/article/doi/10.1093/jtm/taad044/7103514
42. Bakare EA, Onasanya BO, Hoskova-Mayerova S, Olubosede O. Analysis of Control Interventions against Malaria in communities with Limited Resources. Analele Univ "Ovidius" Constanta - Ser Mat. 2021 Jun;29(2):71–91.
43. Xu JW, Lin ZR, Zhou YW, Lee R, Shen HM, Sun XD, et al. Intensive surveillance, rapid response and border collaboration for malaria elimination: China Yunnan's '"3 + 1"'strategy. Malar J. 2021 Dec;20(1):396.
44. Munsense IM, Tsoka-Gwegweni JM. Perceived Health System Challenges of Implementing Cross-Border Malaria Preventive Measures at Ports of Entry in KwaZulu-Natal. Ann Glob Heal. 2023 Apr;89(1).
45. Hussain-Alkhateeb L, Rivera Ramírez T, Kroeger A, Gozzer E, Runge-Ranzinger S. Early warning systems (EWSs) for chikungunya, dengue, malaria, yellow fever, and Zika outbreaks: What is the evidence? A scoping review. Zinszer K, editor. PLoS Negl Trop Dis [Internet]. 2021 Sep 16;15(9):e0009686. Available from: https://dx.plos.org/10.1371/journal.pntd.0009686
46. Herdiana H, Sari JFK, Whittaker M. Intersectoral collaboration for the prevention and control of vector borne diseases to support the implementation of a global strategy: A systematic review. Brooke B, editor. PLoS One [Internet]. 2018 Oct 10;13(10):e0204659. Available from: https://dx.plos.org/10.1371/journal.pone.020465