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REVIEW

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Environmental and socio-economic determinants of malaria transmission in West Africa: a systematic review

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Abstract

Background Malaria remains one of the greatest issues in sub-Saharan Africa.

Methods This study aimed to identify the socio-economic and environmental determinants influencing the transmission of malaria and its incidence in West Africa. A systematic review was conducted using articles published from January 1989 to April 2025, within PubMed and Directory of Open Access Journals (DOAJ) databases. A total of 1145 articles related to our topic were found in the PubMed database, and 125 articles were identified in the DOAJ database. After inclusion and exclusion criteria, 68 articles were selected from both databases.

Results The results indicate that among the environmental determinants, air temperature, rainfall, relative humidity, and vegetation are the most common environmental factors that predict malaria transmission. Moreover, education level, place of residence, housing structure, poverty, and quality of information are the key socio-economic determinants to consider in the prediction of malaria.

Conclusion These factors can be indicators for target programmes for the elimination and prevention of the infection of malaria in West Africa.

Keywords Malaria, Transmission, Environmental factors, Socio-economic factors, Determinants, West Africa

Background

Malaria is an endemic and a severe health problem in sub-Saharan Africa [25]. High mortality rates continue to be a significant public health concern in sub-Saharan Africa [56, 62]. Malaria prevalence in the World Health Organization (WHO) African Region in 2023 was estimated at 263 million cases, accounting for about 94% of cases worldwide. In 2023, there was an increase of 11 million cases, resulting in an incidence of 60.4 cases per 1,000 population at risk, compared to 58.6 cases per 1,000 individuals at risk in 2022 [70].

Malaria is a climate sensitive vector-borne disease, including a number of hydro climatological, biological, socio-economic, and environmental processes [17, 21]. The complexity of malaria determinants makes it difficult

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to predict and control malaria [18]. The environment significantly influences human health outcomes. Unfortunately, in many developing nations, the environment poses a special threat to health [46]. The environment, the climate, and the socio-economic variables are the key determinants of malaria transmission [23].

Despite intensified control and eradication initiatives for malaria, climatic patterns and socioeconomic factors remain important determinants of the dynamics of malaria transmission [37, 62]. Several variables must be examined due to the complexity of malaria transmission [18, 57]. The transmission of malaria including its effects is influenced both by climate and environmental factors [29]. Therefore, changes in rainfall, temperature, humidity, and immunity levels in humans are connected with malaria transmission [28, 36, 53, 66]. Education, poverty, income, health facilities, land use/land cover, quality of information, and urbanization play also a crucial role in the transmission of malaria [35]; [59].

The increasing resistance of mosquitoes to insecticides, alterations in mosquito behaviour owing to control efforts, and ecological disturbances caused by human activities undermine the different efforts for the prevention of malaria. To lessen the burden of malaria on health care systems, there is a need to identify and understand the environmental and socioeconomic factors that affect the incidence and transmission of malaria to mitigate the risk and treatment difficulties. Conducting a systematic review of the socio-economic and environmental determinants of malaria could help to identify the most potential malaria transmission determinants and to possess crucial information for West African malaria control programmes since good environmental management can drastically reduce malaria transmission [38].

Study area

The study area is located in sub-Saharan Africa and includes countries of West Africa. The selected countries for this study are Benin, Burkina-Faso, The Gambia, Ghana, Ivory Coast, Mali, Niger, Nigeria, Senegal and Togo (Fig. 1). The study focused on these countries owing to their highest incidence of malaria. According to the 2023 WHO World Malaria Report, these countries are among the top endemic countries for malaria in West Africa [70].

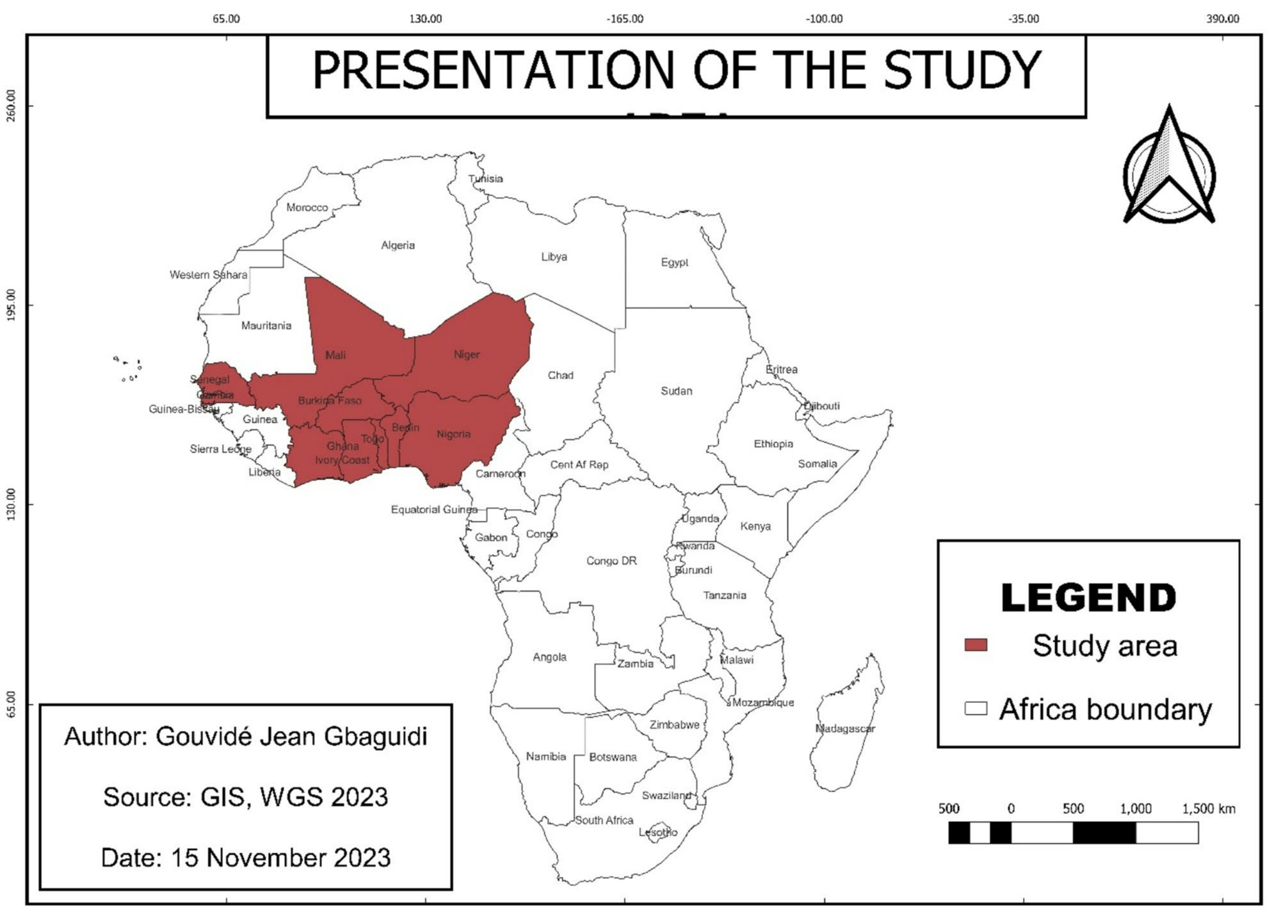

Fig. 1 Map of the study

Methods

This literature review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, ensuring a systematic and transparent methodology for the selection of studies that identify the socio-economic and environmental determinants of malaria transmission in West Africa. The inclusion criteria for this review specified that articles must directly address malaria determinants in West Africa, and only those published in English and French were considered. The included studies were published between January 1989 and April 2025 (Fig. 2).

Two reviewers independently assessed each article. Disagreements were discussed and resolved through consensus. Articles that did not meet the exclusion criteria were excluded at this stage. This process ensured that only studies of acceptable quality and high relevance were included in the final synthesis.

Search strategy

Seven keywords combinations were used based on related articles, systematic reviews, and the authors' existing knowledge. The following keywords were used ("socioeconomic" OR "socio-economic" OR "social" OR "economic") AND ("malaria") AND ("environmental" OR "environment" OR "precipitation" OR "temperature" OR "relative humidity" OR "wind speed") AND ("determinants" OR "factors" OR "influences") AND ("Benin" OR "Burkina Faso" OR "Gambia" OR "Ghana" OR "Ivory Coast" OR "Mali" OR "Niger" OR "Nigeria" OR "Senegal" OR "Togo"). In the PubMed database, 1145 articles related to our topic were found and 125 articles in the DOAJ database. The related articles in the PubMed database start from 1989 to May 2025. On the other hand, the DOAJ database articles start from 1990 to May 2025(Fig. 2). A total of 1270 articles were found related to our topic in the two databases. The use of exclusion and inclusion criteria lead to the selection of 68 manuscripts (Fig. 3; Table 1).

In terms of exclusion criteria, duplicate articles were removed from the dataset and 19 articles that did not specifically focus on the topic were excluded, as well as 1 article that did not concern malaria exclusively. Additionally, we excluded 1067 articles deemed irrelevant to our topic.

To begin, all abstracts and titles were examined to check their inclusion in the second stage which consists of the full screening of each relevant article. After the selection, the final decision was made using a thorough application of the inclusion and exclusion criteria.

Inclusion and exclusion criteria

Inclusion criteria

- Studies that examined the relationship between socio-economic factors and their impact on malaria.
- Studies that investigated the effects of environmental factors (such as climate change, precipitation, temperature, relative humidity, and wind speed) on malaria.
- Research conducted in West African countries, as specified in the search equation.
- Peer-reviewed articles published in scientific journals.
- Studies meeting predetermined quality criteria.

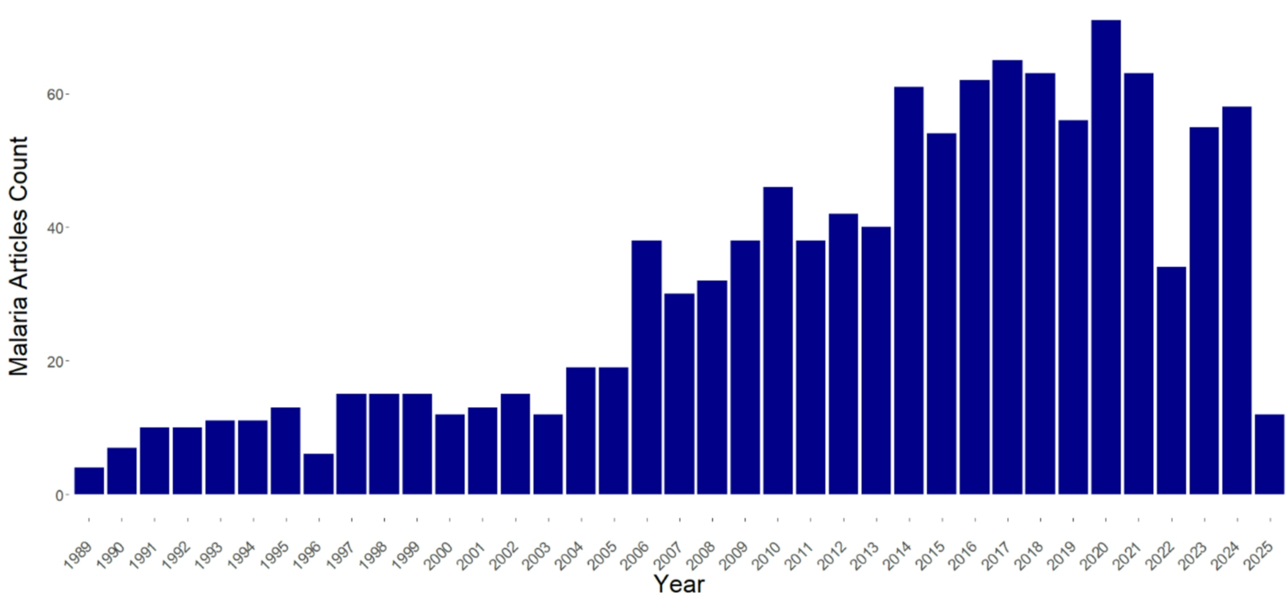

Fig. 2 Publication number of malaria articles from 1989 to 2025 by year in PubMed and DOAJ Databases

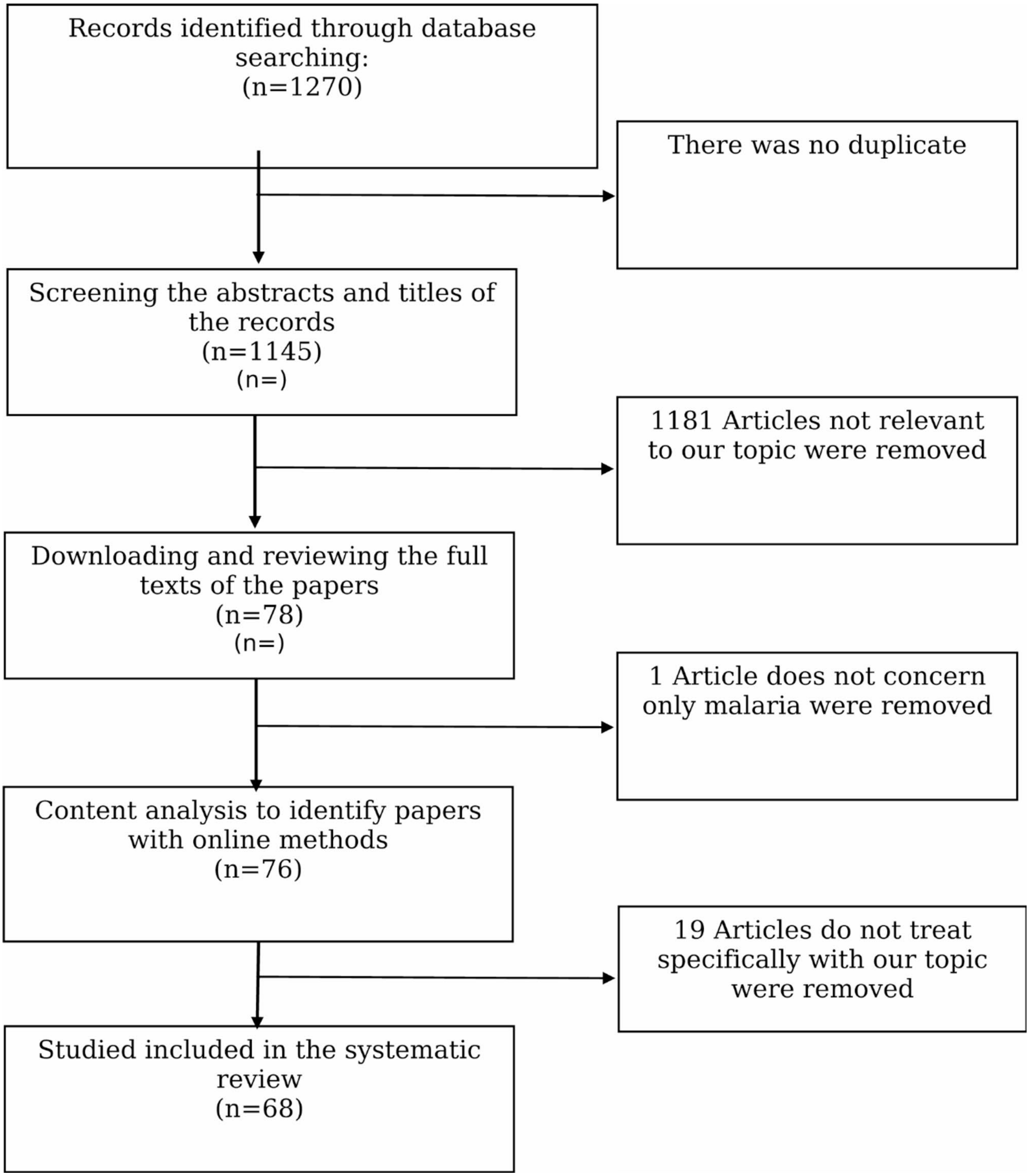

Fig. 3 Flow chart of the inclusion and exclusion criteria

Exclusion criteria

- Articles that did not specifically address the impact of socio-economic factors on malaria.
- Articles that did not examine the relationship between environmental factors and malaria.
- Studies that were not conducted in West Africa.
- Articles that focused solely on either climate change or socio-economic factors without addressing both.
- Studies that did not include any mention of climate change.
- Studies that did not include socio-economic factors.

Table 1 Selected articles after the PRISMA criteria application

Reference	Country	Year	Study Design	Key findings
Ngom et al.	Senegal	2012	Vulnerability assessment	Health sector vulnerable to climate change impacts; malaria highlighted as major concern in Fatick region.
Moiroux et al.	Benin	2013	Modeling	Modeled the risk of being bitten by malaria vectors in a control area, providing insights for vector management strategies.
Klutse et al.	Ghana	2014	Ecological assessment	Assessed patterns of climate variables and malaria cases in two ecological zones, highlighting the interplay between climate and disease incidence.
Labbo et al.	Niger	2016	Field-based ecological study	Field-based ecological study Identified key breeding sites of urban malaria vectors in Niamey; Anopheles gambiae complex was predominant; suggested urban environmental factors play a role in vector proliferation.
Traore et al.	Mali	2017	Interaction study	Investigated interactions between environment, nutrient-derived metabolites, and immunity related to malaria susceptibility in local populations.
Anyanwu et al.	West Africa	2017	Qualitative study	Explored the role of socioeconomic factors in the development and spread of anti-malarial drug resistance, emphasizing the need for community engagement in malaria control efforts.
M'Bra et al.	Côte d'Ivoire	2018	Impact study	Investigated the impact of climate variability on malaria transmission risk, finding significant correlations with rainfall patterns.
Gbalégba et al.	Côte d'Ivoire, Mauritania	2018	Cross-sectional surveys	Assessed asymptomatic malaria case rates in Korhogo and Kaedi. Found low prevalence of clinical malaria episodes with a significant proportion of asymptomatic carriers.
Sondo et al.	Burkina Faso	2020	Molecular epidemiology	Investigated determinants of Plasmodium falciparum multiplicity of infection and genetic diversity, revealing significant influences from environmental factors.
Ateba et al.	Mali	2020	Predictive Modeling	Developed a novel approach using functional generalized additive models to predict malaria transmission dynamics in Dangassa.
Nwaneli et al.	Nigeria	2020	Hospital-based study	Assessed malaria prevalence and sociodemographic determinants among febrile children in a developing community, revealing significant associations with socio-economic factors.
Olukosi et al.	Nigeria	2020	Cross-sectional study	Investigated socio-economic behavioral indicators of malaria parasitaemia among pregnant women attending antenatal clinics, highlighting significant risk factors.
Ndiaye et al.	Senegal	2020	Mapping	Mapped breeding sites of Anopheles gambiae s. l. in areas of residual malaria transmission in central western Senegal. Found a correlation between larval breeding sites, rainfall, and soil characteristics.
Moiroux et al.	Côte d'Ivoire	2012	Quantitative (modelling study)	Demonstrated that vector densities vary significantly by time and location; emphasized the utility of advanced modelling for better control strategy planning
Thomas et al.	Togo	2021	Time series analysis	Analyzed seasonality of confirmed malaria cases from 2008 to 2017, identifying trends by health district and target group.
Akinbobola and Hamisu	Nigeria	2022	Climate variability study	Explored the relationship between malaria and climate variability in northern Nigeria, identifying critical climatic factors influencing transmission dynamics.
A. Akinbobola and S. Hamisu	Nigeria	2022	Time Series Analysis	Malaria incidence is associated with local weather factors, but at different lag times and in different directions for Jos and Kano. Local weather factors affect malaria occurrence more strongly in Jos than Kano.
Mooney et al.	The Gambia	2022	Comparative study	Analyzed dry season prevalence of Plasmodium falciparum in asymptomatic Gambian children, comparing diagnostic methods and implications for surveillance.
Gbaguidi et al.	Benin	2024	Modeling	Developed an intelligent malaria outbreak warning model for northern Benin, integrating environmental and socio-economic data.
Okafor et al.	The Gambia	2025	Projection study	Projected future malaria prevalence based on climate scenarios, emphasizing the need for proactive measures in malaria control strategies.
Salako et al.	Nigeria	1990	Review	Reviewed historical perspectives on malaria in Nigeria, providing context for contemporary challenges.
Gaudart et al.	Mali	2009	Modeling	Modeled malaria incidence with environmental dependency in a Sudanese savannah area. Found that seasonal pattern of P. falciparum incidence was significantly explained by NDVI with a 15-day delay.
Dery et al.	Ghana	2010	Spatio-temporal Analysis	Analyzed patterns and seasonality of malaria transmission in forest-savannah zones, identifying high-risk periods and environmental correlates.
Krefis et al.	Ghana	2011	Modeling	Modeled the relationship between precipitation and malaria incidence in children, identifying critical thresholds for malaria transmission.

Table 1 (continued)

Reference	Country	Year	Study Design	Key findings
Gadiaga et al.	Senegal	2011	Ecological Study	Studied the ecology of urban malaria vectors in Dakar, identifying key environmental drivers of vector populations.
C. Donovan, B. Siadat, and J. Frimpong	Ghana	2012	Facility data & Community Survey	Systematic patterns in malaria incidence by season and district are associated with rainfall. Significant differences in malaria incidence by socioeconomic group [5, 6]
Machault et al.	Senegal	2012	Risk mapping	Mapped risks of Anopheles gambiae densities using remote-sensed environmental data, identifying urban areas as significant hotspots for malaria transmission.
Okebe et al.	The Gambia	2014	Case control study	Conducted a comparative case-control study to identify determinants of clinical malaria, emphasizing key risk factors and potential intervention strategies.
Dieng et al.	Ghana	2014	Ecological study	Assessed patterns of climate variables and malaria cases, revealing significant associations between climate and disease incidence.
Endo and Eltahir	African villages	2016	Modeling	Analyzed environmental determinants of malaria transmission using statistical models, highlighting the significance of climate and socioeconomic factors.
Sissoko et al.	Mali	2017	Temporal Analysis	Studied the temporal dynamics of malaria in a suburban area along the Niger River, highlighting seasonal patterns and environmental influences.
D. U. Nwaneri, A. E. Sadoh, and M. O. Ibadin	Nigeria	2017	Hospital-based Study	Assessed the impact of home-based management on malaria outcomes in under-fives, showing improvements in care and treatment outcomes.
Nwaneri et al.	Nigeria	2017	Hospital-based study	Evaluated the impact of home-based management on malaria outcomes in under-fives at a tertiary health institution, revealing significant improvements in care.
Mattah et al.	Ghana	2017	Cross-sectional surveys	Assessed diversity in breeding sites of Anopheles mosquitoes in urban areas, highlighting the influence of urbanization on malaria transmission dynamics.
Ouedraogo et al.	Burkina Faso	2018	Spatio-temporal Analysis	Analyzed the spatio-temporal dynamics of malaria in Ouagadougou, identifying seasonal peaks and environmental correlates from 2011 to 2015.
Millar et al.	Ghana	2018	Bayesian analysis	Identified local risk factors for residual malaria using Bayesian model averaging, enhancing understanding of transmission dynamics.
Owusu et al.	Ghana	2018	Knowledge, attitudes, practices study	Investigated knowledge, attitudes, and practices regarding malaria among people living with HIV in rural and urban Ghana, highlighting gaps in awareness and preventive measures.
Magombedze et al.	Mali	2018	Mathematical modeling	Developed mathematical models to explore the impact of different dry-season mosquito survival strategies on vector population dynamics. Including aestivation in the model significantly improved the ability to reproduce observed seasonal dynamics.
Okunlola and Oyeyemi	Nigeria	2019	Spatio-temporal analysis	Conducted a spatio-temporal analysis of malaria incidence and environmental predictors, revealing significant associations between rainfall, temperature, and malaria cases.
Rouamba et al.	Burkina Faso	2019	Socioeconomic analysis	Investigated socioeconomic and environmental factors associated with malaria hotspots, revealing that poverty and inadequate housing conditions contribute to malaria risk.
Segun et al.	Nigeria	2020	Statistical Modeling	Higher malaria incidence in months with highest rainfall (June-August). Humidity positively correlated with malaria cases, while temperature showed a negative correlation.
Diouf et al.	West Africa	2020	Climate variability study	Analyzed climate variability and its impact on malaria incidence across West Africa, emphasizing the need for adaptive strategies in malaria control.
Taconet et al.	Burkina Faso	2021	Machine learning modeling	Applied data-driven machine learning to explore environmental determinants of malaria vector biting rates, achieving high predictive accuracy.
Yaro et al.	Burkina Faso	2021	Risk factors analysis	Identified risk factors associated with house entry of malaria vectors in areas with persistent malaria transmission and insecticide resistance.
Gouzile et al.	Côte d'Ivoire	2022	Multicriteria Analysis	Mapped malaria risk related to climatic and environmental factors, providing insights for targeted interventions.
Fall et al.	West Africa	2023	Modeling	Used the VECTRI model and CMIP6 data to enhance understanding of climate change impact on malaria in West Africa.

Table 1 (continued)

Reference	Country	Year	Study Design	Key findings
Chiziba, C. et al.	Nigeria	2024	Secondary Data Analysis	Identified that socioeconomic factors, such as wealth and maternal education, significantly impact malaria risk in urban areas. Recommendations include addressing environmental factors and improving housing conditions for better malaria control.
Asifat, O. A. et al.	Nigeria	2025	Cross-Sectional Survey	Found that unimproved sanitation facilities were not significantly associated with malaria infection after adjusting for socioeconomic factors. Poverty and maternal education were strong predictors of malaria risk among under-five children.
Klinkenberg et al.	Ghana	2006	Cross-sectional survey in urban settings	Urban malaria exists and is associated with anaemia in children. Malaria prevalence was heterogeneous and linked to poor housing and environmental conditions. Urges the need for targeted interventions in urban areas.
Kasasa et al.	Ghana	2013	Spatio-temporal study	Investigated spatio-temporal malaria transmission patterns in Navrongo, highlighting the influence of environmental factors on malaria incidence.
Coulibaly et al.	Mali	2013	Spatio-temporal analysis	Analyzed malaria transmission dynamics within a season in Bandiagara, revealing significant seasonal fluctuations and environmental impacts.
Diabaté et al.	Burkina Faso	2014	Cross-sectional study	Studied ownership and utilization of insecticide-treated nets among under-five children post-mass distribution, revealing gaps in coverage.
Sonko et al.	The Gambia	2014	Analysis	Examined socio-economic status differentials in malaria parasite prevalence, emphasizing the need for targeted interventions.
Kate et al.	Nigeria	2014	Cross-sectional content evaluation	Assessed the quality of malaria-related health information on Nigerian websites; found a general lack of reliability and comprehensiveness, recommending improved digital health communication strategies.
Eteng et al.	Nigeria	2014	Cross-sectional household survey	Ownership and use of insecticide-treated nets (ITNs) were significantly associated with socio-economic status. Households with higher SES and education levels were more likely to own and use ITNs.
Saleh et al.	Nigeria	2018	Secondary data analysis (Survey)	Found discrepancies between net ownership and utilization; lower utilization rates were associated with higher malaria prevalence
Otte Im Kampe et al.,2015	Burkina Faso	2015	Spatio-temporal Analysis	Examined seasonal and temporal trends in all-cause and malaria mortality in rural Burkina Faso from 1998–2007.
Ankrah et al.	Ghana	2016		Review Reviewed malaria control mechanisms, emphasizing the role of GIS in effective healthcare delivery.
Canelas et al.	West Africa	2016	Literature review	Conducted a systematic literature review on spatial analysis of environmental risk factors for malaria transmission, highlighting significant variables.
Epopa et al.	Burkina Faso	2019	Longitudinal entomological and epidemiological study	Seasonal fluctuations in vector species (mainly An. coluzzii and An. gambiae s.s.) significantly influenced malaria transmission. Peak transmission occurred during the rainy season. Highlights the importance of considering seasonality in vector control.
Jane Ugwu and Zewotir	Ghana	2020	Statistical modeling	Evaluated the effects of climate and environmental factors on malaria spatial distribution among under-5 children using generalized additive models (GAMs).
Dieng et al.	Senegal	2020	Spatio-temporal analysis	Investigated spatio-temporal variation of malaria hotspots, providing insights for targeted interventions.
Saleh et al.	Nigeria	2020	Pilot surveillance study at Patent Medicine Vendors (PMVs)	PMVs are a potential surveillance point for malaria monitoring. Most cases confirmed by rapid diagnostic tests were not reported to health authorities, suggesting underreporting in national systems.
Habermann et al.	Ghana	2024	Quantitative (cross-sectional survey analysis)	Found that wealthier households had lower childhood malaria risk largely due to behavioural (e.g., bed net use) and socio-structural factors (e.g., housing quality)
Kombate et al.	Togo	2024	Spatial epidemiFological mapping study	Used geospatial analysis to assess malaria risk among children under five; identified high-risk zones and highlighted the importance of targeted interventions.
Mhelembe et al.	Nigeria	2025	GLMM approach	Assessed the influence of socioeconomic and environmental variables on malaria risk among children under five, employing a Generalized Linear Mixed Model approach.

Table 1 (continued)

Reference	Country	Year	Study Design	Key findings
Millogo et al.	Burkina Faso	2025	Cross-sectional community-based assessment in two malaria transmission settings	Communities in high and low malaria transmission zones displayed different levels of resilience. Structural and social factors (like access to healthcare and community mobilisation) strongly influenced adaptive capacity and response to malaria.
Ogidan et al.	Nigeria	2025	Secondary data analysis using 2021 Malaria Indicator Survey (mixed-effect model)	Ownership of insecticide-treated nets (ITNs) among women of reproductive age was influenced by socioeconomic status, education level, and geographical location. The study recommends targeted interventions to improve ITN ownership in underserved areas.

- Duplicated studies identified across the databases.
- Studies that did not meet acceptable quality standards as defined in the criteria.

Results and discussion

Environmental determinants

Precipitation

Climatic factors control the malaria transmission in West Africa [15, 68]. The spread of malaria is controlled by rainfall patterns and the distribution of particular environmental triggers, potholes, shallow excavations, bottles, and receptacles are good nesting grounds [39]. These parameters modify the multiplication and abundance of the population of mosquitoes, the length of the parasite lifecycle during mosquito maturation, malaria dynamics, and the occurrence of outbreaks in low-endemic regions [34]. Mosquito abundance was greatly influenced by rainfall [66] and is abundant in the rainy season associated with malaria peak [11, 25, 64].

There is a significant link between rainfall variation, temperature and malaria [1, 15, 16, 32, 39]; [59]. Precipitation with high-resolution predicts accurately the incidence of malaria [34, 51]. Rainfall and its intensity were found to influence the transmission of malaria [21]. Land use especially the type of vegetation modifies also the distribution of mosquitoes [46]. As a result, the conclusion of the wet season is marked by extensive occurrence of malaria [10, 24]. Several authors found that the incidence of malaria is elevated in the rainy season compared to the dry season. This is due to the presence of ditches and water in ponds, gutters, and canals and the presence of vegetation surrounding the living areas, work places, and construction sites [1, 15]. Such conditions increase the mosquito reproduction and, in turn disease transmission [18]. The duration of the wet season is a key element in malaria transmission since mosquito populations take time to increase [18]. In West Africa, malaria occurrence rises gradually after the first rains, peaking in the rainy season in October, but the peak was observed between August and September [46, 69].

In contrast, heavy rainfall wipes away many of the development spots of vectors of mosquitoes of malaria parasites [53], and may also flush away the developing larvae, reduces the number of parasite vectors [28]. Development habitats become constantly flooded, and the runoff of water causes the death of larvae [34, 46]. However heavy rainfall may also later results in the formation of temporary or permanent pools and puddles that are developmental grounds for mosquito larvae and abundant vector populations [2, 26] Malaria transmission requires at least 80 mm of rain in four months with average temperatures [26].

A deeper comprehension of the association between malaria incidence and rainfall variation is therefore crucial for successful climate change adaptation techniques that include disease control intervention planning and implementation [32].

Air temperature

Climate change is expected to have a greater influence on human health, especially the prevalence of water-related and vector-borne diseases notably malaria [32]. Rainfall, temperature, and relative humidity predict the incidence of malaria because of their influence on direct or indirect malaria transmission [1, 8].

Temperature influences malaria transmission, and it has a potential and positive impact on malaria incidence [8, 53]; [59]; Thomas et al., [68]. The link between the distribution of malaria vectors and temperature is complex(Moiroux, Bio-Bangana, et al., [43]). A favorable influence of minimum temperature on malaria transmission, suggests that the development of mosquito is usually disturbed at an elevated temperature, as higher temperatures could reduce the anopheline mosquitoes growth, the incubation period as well as the viral rate of development [28]. Where temperature is limiting during the colder season, mosquito populations are high at the onset of rain, with steadily rising temperatures, due to protracted developmental cycles [39]. Temperatures above 30 °C or close to 40 °C reduce mosquito survival, hence their density and loss of some mosquito [29, 37, 38, 62, 63]. The reduction temperatures favours malaria transmission, while rising temperatures have a negative impact [57, 67]. A part from larval growth, temperature influences many aspects of the mosquito life cycle such as biting activity, and adult survival [11]; Moiroux, Bio-bangana, et al., [43]; Taconet et al., [66].

Air temperature can also influence water temperature; a higher water temperature is not linked to the existence of Anopheles larvae but is connected to the larvae density in a collection [22]. Temperature controls the duration of mosquito larvae development in the environment and the development of the parasite within the vector (Moiroux, Bio-bangana, et al., [43]; Okunlola & Oyeyemi [53].

Relative humidity

Climate and environmental factors influence malaria transmission [29]. Relative humidity is one of the important determinants of malaria transmission and malaria incidence. Relative humidity also plays a dominant role in the prevalence of malaria [1, 8].Malaria transmission is positively associated with humidity [59]. The increase in malaria incidence is linked to humidity [24, 57]. A range 60-86% of relative humidity is most favourable for mosquitoes *Anopheles* to thrive and transmit the *Plasmodium* parasite [5, 62].

Wind speed and direction

Wind speed is among the environmental factors to be considered in the prediction of malaria. There are no significant relationships between malaria incidence and wind speed [57, 68]. Although *Anopheles* mosquitoes can fly 10 km, and be carried by wind much further, dispersal studies have shown that 95% do not move than 2 km [68]. This flight range allows them to search for hosts, breeding sites, and suitable environments. Wind can carry mosquitoes much farther than their active flight range. This means that even if a mosquito does not actively fly long distances, it might still be found far from its original location due to wind currents. Otherwise, because high wind speeds are associated with drought and high temperatures, studying the impact of wind independent of temperature and dryness is difficult [57]. Mean wind speed < 1.8 m/s is associated with a higher malaria incidence [5].

Vegetation

Malaria occurrence is impacted by environmental and social variables. Taking into account these data on these parameters into existing malaria control programmes would aid in the creation of sustainable malaria control policies tailored to the local context [59]. Vegetation is a predictor of malaria transmission [29]. Low-floating vegetation is a favourable factor for mosquito larvae occurrence [22].

Normalized Difference Vegetation Index (NDVI), and the Enhance Vegetation Index (EVI) are environmental factors used for malaria prediction in West Africa [13, 17, 29]. NDVI presents significant and positive associations with climatic factors, such as precipitations in Sudanese savannah environments, especially [29, 66]. Increasing surfaces of grassland areas and the percentage of landscape occupied by forest increase the presence or abundance of mosquitoes and are considered aggravating biting risk factors [66]. In areas beside vegetation or to forests (≤ 500 m), the risk of becoming a hotspot only increases when rainfall exceeds 10–15 mm per week [14]. Agriculture in urban areas contributes to the rise in the number of developmental sites, and thus, malaria transmission. Living close to crop marsh areas increases the risk of malaria infection. Normalized Difference Vegetation Index, vegetation cover is highly associated with an increase in biting rates and directly with malaria incidence [29, 36]. A monthly NDVI unit is associated with the monthly increase of malaria count [66]. The EVI is considered a proxy of the development of the habitat of mosquitoes and the physical environment is strongly correlated with disease environments in determining the intensity of a childhood exposure to infectious diseases such as malaria [28], Maize farm increases the risk of malaria infection. In addition, maize pollen constitutes a good nutritional source for *An. gambiae* larvae and has been connected to an elevated incidence of malaria [14].

Surface water and soil moisture

Water bodies can be favourable developmental grounds for mosquito abundance in neighbouring compounds [1, 71]. Perpetual sources of water are adequate to increase the likelihood and abundance of *Anopheles* mosquitoes [33, 66].

Anopheles mosquitoes may grow in areas where there is stagnant water for a minimum of 10–15 days, and larval is high in density where there are rivers, and water pools [19]. Furthermore, the presence of small stagnant pools of water in the rainy seasons or at the start of the dry season favours the survival of mosquito and the development of larvae [28].

Variation in river levels is related to malaria incidence [63]. Saline or partially saline hydromorphic and holomorphic soils is good indicator for the retention of water. These types of soils constitute potential larval developmental sites [46]. Soil moisture or Normalized Difference Water index (NDWI) increases the malaria infection risk [26]. Paved drains, puddles, and ditches/dugouts are permanent developmental sites [38].

The proximity to water with vegetation has a positive effect on malaria incidence [53]; [59]. Malaria risk is significantly higher among children near hydrographic networks [7].

Variation of the density of *Anopheles* mosquito larvae is related to the chemical, physical, and biological compositions of water in the diverse ecosystems [38]. The quality of water controls the development of mosquito larvae. The incidence of malaria can be low when the physicochemical parameters are not suitable for the development of mosquitoes [25].

Elevation

Environmental factors influence aggressiveness and vector mortality, together with the incidence of malaria [23]. Improving information and understanding of the environmental factors that control the abundance of malaria vectors and their distribution can help develop tailored interventions for the control of malaria vectors [2, 66]. The topography also influences malaria transmission and landscape variables are correlated with the vectors' biting rates [66, 68].Elevation is used as a primary predictor of the presence and abundance of *Anopheles* mosquitoes and indirectly helps to determine the intensity of malaria risk.

Malaria infection is lower at higher altitude, and areas below 500 m are associated with elevated risk of malaria incidence. Altitude could indirectly influence the spread and distribution of malaria through its effect on temperature. The infection of malaria does not occur at specific altitudes due to elevated temperatures, which are unfavourable to the parasite's life cycle [13].In addition, the existence of water bodies decreases with the rise in altitude.

Land use land cover (LULC)

In West Africa, good management of land can help to improve malaria control. Land cover/land use are potential factors in malaria prevention [63]. Many activities contribute to changes in land use, the expansion of cities into new residential areas. The development of agriculture in urban areas, contribute to the increase in the number of development sites, which has an impact on malaria transmission [33].

The influence of urbanization on malaria risk in African cities is significant. Increasing housing density, and reducing non-polluted water resources [35, 41]. The prevalence of malaria is high in rural areas owing to the increase in crops, which provide a suitable platform for the development of mosquitoes [48]. Proper environmental management through good land use can reduce mosquito developmental sites in rural and urban areas [38, 48].

Socio-economic determinants

Level of education/ knowledge about malaria

Socioeconomic factors have a significant impact in the control of malaria infection.Education is an important predictor of the prevalence of malaria, and the population education level benefits public health [54]. The level of education affects the ability to read and comprehend written instructions describing how to use anti-malarial medications; otherwise, malaria information determines preventive and treatment-seeking attitudes. An educated community may be capable of recognizing the crucial role of Insecticide-Treated Nets (ITNs) in malaria prevention and comprehending the information contained in outreach efforts [3, 20]. Lower educated communities perceive a greater threat of malaria than the most educated. Educated mothers have a positive effect on their children's health [12, 48]. This is because they may possess a deeper comprehension of health-related issues, which will affect their approaches to disease prevention and care-seeking conduct [48, 54].

Gender/Age

Gender is linked with the incidence of malaria infection, and in general female predominance is noted. Children are particularly prone to malaria than adults [45, 61]. In rural areas, malaria affects males more than females [65]. The use of ITN is also elevated in households when mothers maintain the house and eradicate stagnant water and larval breeding grounds from the surrounding environment. This shows that activities done by women to reduce mosquito density are often combined with actions taken to safeguard their children and may represent a broader concern among mothers regarding avoiding malaria at home [12].

A child's age is an independent predictor of his or her malaria status; little children have less skin surface subjected to mosquito bites and so are less susceptible to transmission of malaria. Otherwise, children under the age of five are more vulnerable to malaria infection. The age spectrum of malaria is linked to different types of health-care participation by age group based on socioeconomic status and access to care facilities.

Place of residence/ housing structure

Socio-economic factors like place of residence and settlement style constitute structural factors that can enhance the health of the community. These facets are considered to influence how malaria therapy is thought of and how anti-malarial medications are used [3]. Improve the quality of the house can significantly decrease the incidence of malaria. Housing building supplies (type of floor, window, wall and roof) have a strong connection with the likelihood of infection in a number of ages, though this is only confirmed in the overall population of substandard wall materials for housing [65]. Metal roof houses have fewer hotspots of malaria in contrast to thatch roof dwellings; this might be the effect of the internal environment of the different types of buildings [71]. In addition, metal roof houses are typically warmer and less humid than thatch roof buildings, which might hinder the lifespan of vectors of malaria laying indoors. In addition, roofs made of metal can simply be an indicator of a higher-quality home that is less permeable to mosquitoes, as metal roof houses are frequently better built with fewer mosquito entrance sites than thatch-roofed buildings [71].

The prevalence of malaria in rural areas is prominent than in urban areas [40]. This could be attributed to differences in socioeconomic characteristics such as educational level, occupation, and health coverage [58] The variety and number of house entries may increase the danger of getting bit by mosquitoes and becoming infected with malaria [3, 49, 52]. Doors and windows are screened to prevent mosquito-human contact, and combined environmental control is used [52]. Independent of land ownership, malaria risk is greater in lightly urban areas than in tightly built-up regions [7].

Poverty

Malaria is frequently linked to poverty. Macro-level figures demonstrate strong linkages between poverty and malaria, and new data suggests that the causal association between malaria and poverty is bidirectional [42]. The income level affects the choice of where to seek medical attention for malaria and whether or not to utilize a malaria screening prior to treatment [3]; [40]. The risk of malaria can be lessened when the household's economic situation is good, which means that they have a higher income [52]. Living conditions are closely linked to malaria transmission [47]. Children under five from low-income families face a significantly higher burden of malaria [4].

Socioeconomic factors serve a substantial part in identifying anti-malarial drug use habits that foster drug resistance; impoverished communities use cheaper malaria prevention methods than more prosperous socioeconomic groups, and they are more exposed to the bite of mosquitoes [50]. This makes them more likely to contract malaria [55]; [16]. Furthermore, when compared to lower socioeconomic categories, the wealthy spend more on window and door nets because housing structure plays an important role in the control of malaria [4, 6].

The economic status of the community contributes to bed net use where the distribution of bet nets is not free. Ownership of bed nets is higher in households with good economic status. Households with a good wealth index have the lower odds of malaria. This can be justified by their ability to buy easily ITNs to use for the prevention of malaria [52].In contrast, children from poor households have a higher incidence of malaria because these households do not have enough ITNs [20]; Saleh et al., 2020).

Urbanization

Increased urbanization will not necessarily contribute to reduce malaria. Malaria epidemics may continue to be a life-threating issue in densely populated places, impacting an increasing number of individuals [31]. Malaria transmission is higher in communities located nearer to the periphery of urban areas than in a highly inhabited and polluted centre metropolitan areas [31]. Malaria incidence is lower in urban areas than in rural areas, primarily due to improved socio-economic and environmental conditions in urban settings [9]. Housing is expected to be a proxy for a high human population density, resulting in an attenuation of *Anopheles* bites and indirectly improving the control of malaria infection [27, 36]. In addition, variances in malaria incidence may be explained by variances in population growth, and migration. Urban children have lower odds of malaria transmission due to the presence of pharmacies, the exposure to TV in order to be informed about all the news concerning the transmission of malaria [32, 60].

Quality of information

Malaria early warning information is a key factor in the prevention of malaria infection. Good and early information can help to take preparedness action to prevent the risk of being infected by malaria. Enhancing the standard of malaria-related health knowledge may result in communities becoming empowered by engaging and aiding them in improving their social communication and assistance. Individuals ought to be offered knowledge that will enable them to handle their health, and the internet serves as a helpful instrument in doing so [30]. The use of the internet to share daily information with the community and exposure to TV prevention campaigns may potentially save millions of lives [59].

In addition, the use of Geographic Information Systems (GIS), with the improvements in technology over the last three decades, has enabled researchers to run preliminary research readily and swiftly [8].

Health facilities

Other factors, such as hospital accessibility, may influence transmission [34]. The positive link between malaria risk and distance to the closest healthcare facility gets high after 2–4 km [41].

Indigenous knowledge can help improve malaria prevention when the prescription is fair. Self-medication and herbal/traditional treatment depend on health insurance status and place of residence [6]. Disparities in malaria age distribution are related to health facility attendance in different regions of the city and depend on socioeconomic status and health-care access [27].

Discussion

Climatic and environmental daterminants

This study aimed to identify the environmental and socio-economic determinants influencing the transmission of malaria and incidence in West Africa. Environmental factors such as rainfall, temperature, relative humidity, and vegetation are positively associated with malaria incidence [39]; [59]; Sondo et al., [64]. Although rainfall impact is highly dependent on intensity and temporal distribution [14, 18, 34]. Moderate rainfall can create breeding habitats by forming stagnant pools [36, 38], while heavy rainfall can wash away existing breeding sites and reduce mosquito populations [1, 53]. The persistence of malaria transmission at the end of the rainy season is often attributed to the proliferation of mosquito larvae [10].

Temperature is the primary cause of mosquito abundance and malaria transmission [11, 29]; [59]. While temperature variations influence mosquito spread, elevated temperatures can decrease mosquito survival rates and population densities [29, 39, 63]. Increasing air temperature can increase the surface water temperature of the developmental sites and lessen the suitability conditions for the spread of mosquitoes, and decline malaria transmission over the dry season [34, 38]. Mosquito survival depends on specific temperature ranges that vary by region.

Furthermore, sustained relative humidity can allow malaria transmission to persist even during the dry season. Dense vegetation provides ideal breeding and resting environments for mosquitoes, contributing to higher malaria transmission intensity, [22, 23]. The condition of vegetation, often dependent on weather patterns, serves as a predictor of malaria prevalence [14].

Wind speed is one of the environmental factors to be considered in the prediction of malaria, even though there is no significant relationship between wind speed and the incidence of malaria [57, 68]. Wind speed can contribute to the increase in malaria transmission because mosquitoes can fly over 10 km. The presence of surface water bodies provides favorable breeding grounds for mosquitoes, contributing to their abundance in surrounding areas [1, 29, 38]. Increasing air temperature can modify the suitability of these water bodies for mosquito spread. The duration of water bodies is also important before being considered as mosquito developmental sites because the lay and the development of mosquito larvae required some number of days [47]. The proximity to water with vegetation provides ideal developmental sites for Anopheles mosquitoes, and this has a positive effect on malaria incidence [44, 57]; [59]. The suitability of these water bodies for mosquito development depends on factors such as rainfall patterns (duration, intensity, and distribution), altitude, and water quality, all of which influence Anopheles larvae survival and variation. Good management of surface water can reduce the transmission of malaria [38].

Higher altitudes are generally associated with lower malaria transmission due to a reduction in suitable mosquito breeding sites and increased air temperatures that are less favorable for larval development [13]. Urbanization in African cities has a major influence on malaria transmission and incidence [35, 41]. Conversely, increased housing density in well-managed urban environments with effective water sanitation, closed drainage systems, and access to potable water can reduce mosquito breeding sites and, consequently, malaria transmission. Proper environmental management through good land use can help to reduce mosquito breeding sites in urban and rural areas [38, 48].

Socioeconomic determinants

Education plays a major role in the prediction of malaria transmission [54]. Areas with higher education level are characterized by lower risk of malaria transmission. Children under five years of age are particularly vulnerable to malaria due to their developing immune systems [25, 45]. Children from mothers with high education levels will be exposed to lower malaria risk because educated mothers have good health care seeking to protect their children. Children in rural areas may face a higher risk of malaria compared to their urban counterparts due to differences in parental education levels and access to healthcare [12]. However, children over five years old can also be vulnerable if they lack access to adequate healthcare and are exposed to malaria parasites [48]. Gender association with malaria infection depends on the area. In some areas, females can be the most vulnerable and in other parts the male. In the general case, female is the predominant because of their limited adaptative capacities. In addition, place of residence and housing structure are strongly associated with malaria risk infection [65]. Rural populations often face a higher malaria risk due to factors such as lower adaptive capacity, inadequate housing, and limited access to education Individuals with higher education levels are more likely to understand and implement preventative measures, such as closing doors and windows to prevent mosquito entry [52]. Together with these factors, poverty increases malaria transmission [3]. The income level influences the prevention or malaria control by increasing the incidence of malaria [6].

Quality of information is a key factor in the control of malaria [30]. The dissemination of good information can reduce the risk of malaria. Good information helps the population to take preparedness action to reduce malaria risk. Informed populations are less vulnerable to malaria because they are aware of the risks and know how to take preventative measures.

The health care facility is not a predictor of malaria but can help to reduce the vulnerability of communities to the infection of malaria. Understanding the effects of environmental factors (air temperature, rainfall, relative humidity, and vegetation) on the transmission of malaria can help to fully integrate them in the prevention or control of malaria. Education level, place of residence, housing structure, poverty, and the quality of information are also important in the control of malaria. Some recommendations have been formulated on the topics for future scientific research in the field of climate change and malaria transmission to strengthen malaria prevention action.

In the findings of the work above, environmental and socio-economic factors play crucial roles in the transmission of malaria in West Africa. The potential environmental factors which influence the transmission of malaria are air temperature, rainfall, relative humidity, and vegetation. Besides the environmental factors, socio-economic determinants are education level, place of residence, housing structure, poverty, and the quality of information. Most attention should be given to these factors in malaria control programmes.

Conclusion

The findings of the study highlight that both environmental and socio-economic factors play critical roles in malaria transmission in West Africa. Effective malaria control programmes must adopt integrated approaches that address these multifaceted determinants, considering factors such as air temperature, rainfall, relative humidity, vegetation, education level, place of residence, housing structure, poverty, and access to quality information. Climatic, environmental, and socio-economic factors must be taken into account for targeted malaria control programs. These factors are crucial for the control and elimination of malaria in West Africa.

Recommendations for future studies

Understanding the local patterns of malaria transmission and the effect of climate change or climate variation on the transmission of malaria is crucial for the planning and evaluation of malaria interventions [11].

- Assessing the risk of malaria caused by climate season variation remains an important field of scientific research. The effects of climate change on malaria are very complex and multifactorial. Climate variables and environmental factors should be analysed individually and in relationship with climate change and malaria transmission modeling. This will help to determine the factors influence malaria occurrence now and in future environmental circumstances anticipated by the IPCC.
- Furthermore, a better understanding of the association between the morbidity of malaria, climatic variables, and environmental factors is a good tool to control malaria transmission and strengthen the planning activities of the malaria program.
- In addition, the assessment of the vulnerability of communities to malaria risk will be a good tool for the policymakers and the community to have adapted preparedness responses to reduce the impacts of climate change.

The following relevant research topics are worth highlighting for future scientific research.

i) Malaria modelling at the regional or national level, taking into account regional environmental parameters as well as socioeconomic variability.
ii) Development and validation of malaria early warning model based on environmental factors on many early malaria epidemic forecasting methods.

iii) Assessment of the qualitative factors that affect malaria transmission at different spatial and temporal scales using multidisciplinary perspectives (life science, human science, and biophysics), evaluating interactions, synergism, and nonlinearity between the various factors involved in transmission.
iv) Development of malaria transmission risk maps based on climate-sensible environmental indicators. Based on the research agenda for malaria elimination, this will serve as an analysis guide for the planning and execution of relevant control actions, and integration of regional environmental programmes and socio-economic variation, mainly in West Africa.
v) Assessment of the vulnerability of communities to malaria infection could be an important tool to take target action in specific areas where the population is at high risk of malaria infection.
vi) Development of malaria transmission models to analyse the risks caused by climatic and environmental changes.

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Author contributions
Gouvidé Jean Gbaguidi collected the data, analysed and interpreted the data, and wrote the manuscript. Nikita Topanou and Guillaume K. Ketoh designed the study, verified the data collected, and validated the methods applied. Walter Leal Filho and Komi Begedou reviewed the manuscript, assessed it, and validated the data processing methods. All authors had full access to all the data in the study, took the final responsibility for the decision to submit the manuscript for publication, and approved the final version of this article to be published. The publication search was conducted by Gouvidé Jean Gbaguidi. To ensure a comprehensive and unbiased selection process, any conflicts regarding article inclusion were addressed through a collaborative approach. In cases where disagreements arose, we planned to resolve them by discussing the articles among the research team members, and if necessary, consulting a third author to reach a consensus. This method promotes transparency and ensures that the final selection of studies is robust and well-justified.

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Data availability
Data are available at the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), Université de Lomé. You should contact the corresponding author for the data request.

Declarations

Ethics approval and consent to participate
This study did not involve any human data.

Consent for publication
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