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Determinants of the Dynamics of Malaria Infection Transmission in Mining Areas: Literature Review

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ABSTRACT

Introduction: The incidence rate of malaria globally has seen significant fluctuations over the past few years. According to the World Health Organization's World Malaria Report 2023, in 2022, there were an estimated 249 million cases of malaria globally, exceeding the pre-pandemic level of 233 million in 2019 by 16 million cases. Illegal miners are highly vulnerable to malaria due to their work in remote, ecologically disturbed areas, where their activities create breeding grounds for malaria-carrying mosquitoes, significantly increasing their risk of infection.

Objective: The aim of this literature review is to find the rsik factors of malaria transmission in arrtisanal mining areas population

Method: A PRISMA flow diagram-based has been used to find the most resonant journal research related to malaria transmission in mining areas population. The articles to be analyzed are searched using keywords with Boolean rules such as ("Risk factor" OR "Determinant") AND "Malaria" AND "Transmission" AND ("Mining Area" OR "Mining location"). The chosen papers are the findings of research that meets the objectives and is published in 2020–2024 in English with an international quality

Result: Search results from the PubMed, Google Scholar, and ScienceDirect databases yielded 9 articles selected for review published between 2020 to 2024. Research on these articles was conducted in various countries, including Brazil, Venezuela, Indonesia, Gambia, French Guiana (FG), and other countries. A total of 11 articles were carefully reviewed to gather information regarding risk factor of malaria in mining areas in this literature review.

Conclusion: Improving knowledge, healthcare access, and preventive practices is essential to reducing malaria transmission in high-risk mining areas, particularly where clandestine operations and ecological disturbances are prevalent.

Keywords: Malaria Transmission; Mining Areas; Risk Factors; Determinants

INTRODUCTION

Illegal miners often referred are particularly susceptible to malaria due to a combination of environmental, social, and health-related factors. The illegal nature of their activities frequently places them in remote and ecologically disturbed areas, which are conducive to the proliferation of malaria-carrying mosquitoes. As these miners excavate the land for gold, they create numerous water-filled pits that serve as ideal breeding grounds for the *Anopheles sp.* mosquitoes, the primary vectors of malaria. This disruption of the ecosystem not only increases mosquito populations but also places miners in close proximity to these vectors, heightening their risk of infection (1, 2).

The incidence rate of malaria globally has seen significant fluctuations over the past few years. According to the World Health Organization's World Malaria Report 2023, in 2022, there were an estimated 249 million cases of malaria globally, exceeding the pre-pandemic level of 233 million in 2019 by 16 million cases (3, 4). This increase is attributed to disruptions caused by the COVID-19 pandemic, which led to a surge in malaria cases and deaths in 2020 and 2021(5, 6). The report also highlights that the number of global malaria deaths in 2022 was higher than in 2019, with an estimated 608,000 deaths compared to 576,000 in 2019(7, 8). The WHO African Region carries a disproportionately high share of the global malaria burden, accounting for 94% of malaria cases and 95% of malaria deaths in 2022(4, 9, 10).

The countries that have seen the highest increase in malaria cases recently are Pakistan, Ethiopia, Nigeria, Papua New Guinea, and Uganda. Pakistan experienced the largest increase, with about 2.6 million cases in 2022 compared to 500,000 in 2021. Significant increases were also observed in Ethiopia, Nigeria, Papua New Guinea, and Uganda, with Nigeria recording an increase of 1.3 million cases, Uganda 597,000 cases, and Papua New Guinea noting a substantial rise in malaria cases as well(4, 11, 12).

The socio-economic context of illegal mining also plays a significant role in the malaria epidemic (13). Miners often work in hazardous conditions for minimal pay, driven by the hope of financial gain from gold extraction. This economic pressure can lead to a disregard for health risks, as miners may prioritize work over their well-being. Additionally, the stigma associated with illegal mining activities can deter individuals from seeking help or reporting malaria cases, perpetuating the cycle of infection and transmission (14, 15).

Based on the demographic profile of clandestine miners, young males predominantly between age of 15 - 29, contributes to the transmission dynamics of malaria (16). These individuals often exhibit high mobility, moving between mining sites and regions, which facilitates the spread of malaria beyond local hotspots (17). The lack of preexisting immunity among these populations, combined with their transient lifestyles, means that they are particularly vulnerable to severe forms of malaria, especially when they return to their communities after working in high-risk areas (18, 19).

Populations in mining areas has the highest risk of malaria due to environmental changes that favor mosquito breeding, their demographic characteristics, limited access to healthcare, and socio-economic pressures that prioritize work over health (20-22). Addressing the malaria crisis in these communities requires a multifaceted approach that includes improving healthcare access, enhancing malaria surveillance, and implementing effective vector control measures, all while considering the unique challenges posed by illegal mining activities (14, 23, 24).

METHOD

A PRISMA flow diagram-based literature review was the methodology employed in this investigation. The references for the journal reviews were gathered from Pubmed, ScienceDirect, and Google Scholar. The publications that were chosen are from research that has been done internationally during the past five years. The articles to be analyzed are searched using keywords with *Boolean* rules such as ("Risk factor" OR "Determinant") AND "Malaria" AND "Transmission" AND ("Mining Area" OR "Mining location").

When the search was first conducted using keywords, 322 journals that matched the search terms were located. There were 74 articles that met the screening criteria that looked for a connection between the sort of study conducted in the journals and the topic presented. The chosen papers are the findings of research that meets the objectives and is published in 2020–2024 in English with an international quality. Article pieces in the form of reviews, literature reviews, and pieces lacking a comprehensive framework and explanation are excluded from consideration for selection.

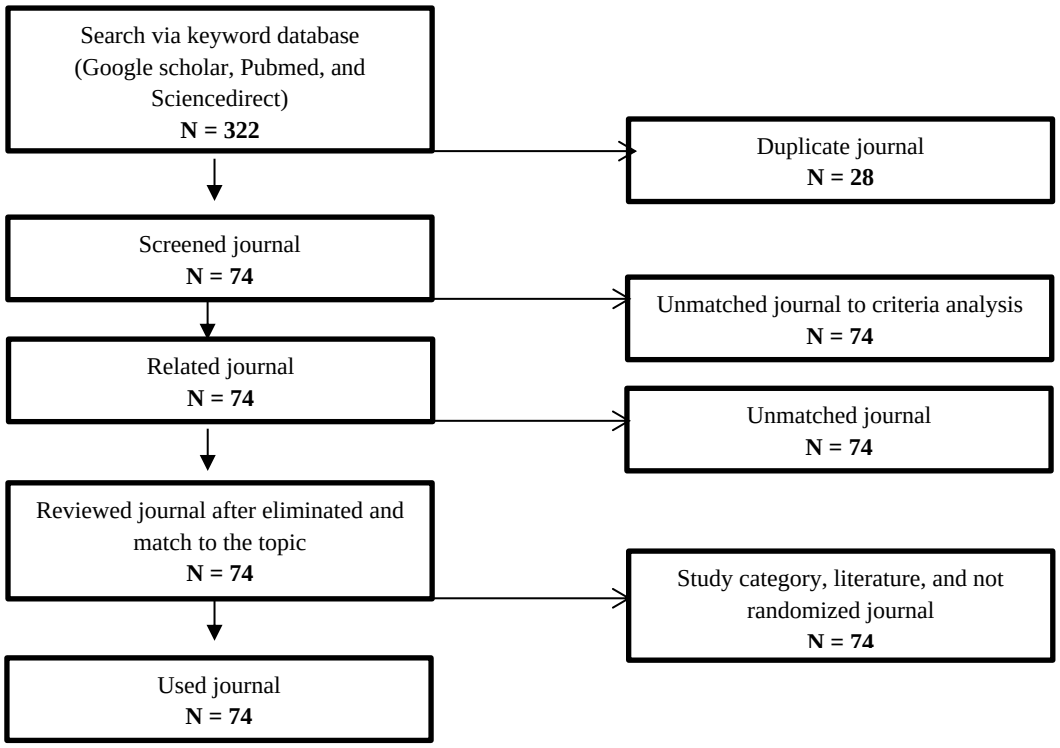

Figure 1. Prism Flow Diagram

From the abstract, objectives, methods and research results, 11 articles were obtained that were relevant to be analyzed for clarifying the determinants of malaria infection transmission among the mining areas.

RESULTS

Search results from the PubMed, Google Scholar, and ScienceDirect databases yielded 9 articles selected for review published between 2020 to 2024. Research on these articles was conducted in various countries, including Brazil, Venezuela, Indonesia, Gambia, French Guiana (FG), and other countries. A total of 11 articles were carefully reviewed to gather information regarding risk factor of malaria in mining areas in this literature review.

The prevalence of malaria in mining areas is particularly concerning because the environment altered by mining activities, such as the creation of pits and stagnant water pools, creates ideal breeding grounds for Anopheles mosquitoes, the main vector of malaria. Miners working and living near these areas are frequently bitten by mosquitoes, increasing the risk of malaria transmission. In addition, difficult access to illegal mining areas makes timely diagnosis and treatment a major challenge. Many miners resort to self-medication with inadequate doses of drugs or use low-quality medicine, which exacerbates the problem of parasite resistance to antimalarial drugs. The combination of environmental factors, poor access to healthcare, and inappropriate treatment practices contribute significantly to the high prevalence of malaria in mining areas.

Table 1. Reviewed Journal

No	Title	PEOS Formula			
		Population	**Exposure) / Cause**	**Outcome**	**Study Type**
1	Impact of Malakit intervention on perceptions, knowledge, attitudes, and practices related to malaria among workers in clandestine gold mines in French Guiana: results of multicentric cross-sectional surveys over time Longchamps et al., 2022	Peoples working on clandestine gold mining sites inGuiana Shield that are French Guaiana (FG) and Suriname.	Low KAP (Knowledge, Attitudes, and Practices) among clandestine gold miners to inervene malaria and seek some help after there are few symptomps	This study shows a signifcant decrease on perception and knowledge towards malaria between 2015 and 2019 concomitant with the decrease in incidence while improved attitudes and practices. It also reveals that participation to the Malakit intervention was associated to improved knowledge and preventive practices related to malaria among gold miners. Tis information is crucial in the context of malaria elimination in Suriname and French Guiana to avoid malaria resurgence.	quasi-experimental design
2	Risk Factors of Malaria Transmission Dynamics Among Sand Mining Workers in the Kombos West Coast Region, The Gambia Jassey et al., 2024	A total of 92 respondents of mining worker in Kombos West Coast Region	Many rural areas since many mosquito species, especially those of the primary malaria vectors, live in aquatic environments.	In the multivariable analysis, age and the presence of mosquito breeding grounds were found to be risk factors for malaria. Conversely, factors that provided protection included having more knowledge, applying insect repellent, and the condition of the walls inside homes.	Quantitative research with cross-sectional type
3	A cross-sectional study investigating malaria prevalence and associated predictors of infection among migrants to a newly established gold mining settlement in the Gambella Region of Ethiopia Glendening et al., 2021	Populations of the reserach are migrants from 84 households in Lunga, Gambella Region of Ethiopia	Migration from highland areas to lowland areas has been highlighted as a potential public health problem in Ethiopia.	Malaria was most common in young children, with those aged 15–24 having 67% lower odds of infection than those aged 0–4. In contrast, people over 25 had a 75% lower chance of contracting malaria. On the other hand, people with lower rates of malaria test positivity who reside in higher altitudes and those who live in homes with five to ten people.	Mix method with qualitative components and quantitative research with cross-sectional survey
4	Training-of-trainers programs for community health workers involved in an innovative and community-based	A total of 20 CHWs participated in the training and the first-step evaluation For the second step,	Low self-management among people involved in artisanal and small-scale gold mining making	Effective and sustained treatments incorporating CHW profiles necessitate training programs that are of the highest caliber, most suitable, and efficacious. A key issue to consider for achieving efficacy	A mixed-method case study was implemented in two steps between February and

No	Title	PEOS Formula			
		Population	**Exposure) / Cause**	**Outcome**	**Study Type**
	intervention against malaria among goldminers in the Guiana shield;a quality and effectiveness evaluation Carboni et al., 2024	four semi-structured interviews were conducted	the transmission of malaria is high	and quality is training design. It has been demonstrated that the training-of-trainers paradigm enables a high degree of satisfaction, good learning outcomes, and satisfactory field implementation.	March 2023
5	Identifying and characterizing high-risk populations in pilot malaria elimination districts in Madagascar; a mixed methods study Gebreegziabher et al., 2024	The study population included patients routinely tested for malaria in 18 health facilities in Antsirabe II and 9 health facilities in Faratsiho that had the highest burden of malaria in 2020	Risk factors among these groups included overnight stays and travel patterns combined with a lack of malaria prevention tools. The treatment cost and distance to the health facility as barriers to care and expressed interest in presumptive treatment and involvement of gatekeepers .	Workers in rice agriculture, outdoor/manual labor, notably miners, and employment requiring travel or overnight stays, especially itinerant vendors, had higher rates of malaria infection in Antsirabe II and Faratsiho districts than other categories. Respondents in Antsiranana I identified students, mobile merchants, and non-rice farmers as HRPs. The study's findings highlight the importance of risky behaviors, service accessibility, preventative instruments, surveillance, and preventative tactics.	Mix method with qualitative components and quantitative research with case-control method
6	Investigating the Yanomami Malaria outbreak puzzle: Surge in mining during Bolsonaro's government triggered peak in malaria burden Dutra et al., 2024	Yanomami people that has been infected malaria by malaria between 2003 and 2023 from the Brazilian Ministry of Health database	The impact of land use on illegal mining, when mining increases by 1%, malaria cases increases by 31%.	The Yanomami experienced up to 15% more cases of malaria than the non-Indigenous populations in the vicinity. This is probably due to the illicit mining activity that has been increasing in their region. Furthermore, we emphasize that preserving a high level of forest cover guards against malaria, hence preserving the health of Indigenous people in the Amazon.	Quantitative research with cross-sectional type
7	Risk Factors of Malaria Transmission in Mining Workers in Muara Enim, South Sumatera, Indonesia	Population study is the villagers 3 village, Tanjung Agung, Tanjung Lalang, and Penyandingan	Behavioural risk factors and environmental risk factors	In addition, using insect repellent, having more education, and the state of one's home walls all help prevent malaria. Thus, it is strongly advised to decrease risk factors and raise	Quantitative research with cross-sectional type

No	Title	PEOS Formula			
		Population	**Exposure) / Cause**	**Outcome**	**Study Type**
	Hasyim et al., 2023			preventative measures through efficient information, education, and communication in order to eradicate malaria in mining areas.	
8.	Malaria prevention and care seeking among gold miners in Guyana Olapeju et al., 2020	Adult miners between the ages of 18–59 years living in mining camps in 3 regions in Guyana	Behavioral outcomes from the miners such as self medication, mosquito net usage, healthcare seeking, and malaria testing	Miners had relatively low rates of malaria preventive and care seeking, which can be attributed to factors such as mosquito net use, perceived norms, malaria education, and confirmed malaria episodes in the past. The study's conclusions have implications for community case management programs that use trained volunteers to provide malaria testing and treatment in order to reduce the spread of malaria among isolated populations that work as gold miners, as well as for the widespread and ongoing distribution of insecticide-treated nets.	Quantitative research with cross-sectional type
9.	Burden of Malaria in Children under-five and caregivers health-seeking Behaviour for Malaria-related Symptomps in Artisanal Mining Communities in Ghana Dao et al., 2021	Caregivers and their children under fve was conducted in three artisanal mining communities in the East Akim District in Ghana.	Artisanal mining creates enabling breeding ground for the vector of malaria parasites. There is paucity of data on the efects of artisanal mining on malaria. This study assessed burden of malaria and caregivers' healthseeking behaviour for children under fve in artisanal mining communities in East Akim District in Ghana.	Children under the age of five who live in East Akim District artisanal mining communities have a considerably greater prevalence of malaria and anemia than children who live in non-artisanal mining areas. In order to reduce the high rate of malaria and enhance health-seeking behavior, interventions are required to effectively control mining activities in these communities and to bolster campaigns for malaria prevention and health education.	Quantitative research with cross-sectional type
10.	Gold miners augment malaria transmission in	All of the people included in Malaria	Illegal mining and difficult access hinder	One fact that has been contributing to the rise of malaria infections in Roraima	An ecological time-series study was based

No	Title	PEOS Formula			
		Population	**Exposure) / Cause**	**Outcome**	**Study Type**
	indigenous territories of Roraima State, Brazil Barros et al., 2022	Epidemiological Surveillance Information System, Mortality Information System and Hospitalization Information System.	malaria control, timely diagnosis, and treatment, leading to self-medication and drug resistance.	is the existence of miners in native regions. It is emphasized again how important it is to put in place health policies that satisfy this need.	on secondary data concerning the number of cases, hospitalizations and deaths from malaria that occurred in Roraima from 2010 to 2020.
11.	Changing Transmissions Dynamics among Migrant, Indigenous and Mining Populations in a Malaria Hotspot in Northern Brazil: 2016 to 2020 Wetzler et al., 2022	All suspected/ confirmes local, imported malaria cases via SIVEP surveillance system	The mining environment creates stagnant air, a breeding ground for Anopheles mosquitoes, increasing the risk of malaria transmission.	These illegal mining regions are at the center of efforts to eliminate malaria because evidence from Venezuela indicates that they not only maintain transmission but also have the potential to revive it after measures have decreased malaria locally or even eliminated it locally in other areas.	Descriptive study that utilizes malaria surveillance data from the Malaria Epidemiological Surveillance and Case Notification Information System (SIVEP-Malaria) in Brazil from 2016 to 2020.

DISCUSSION

Behavioural Factors and Healthcare Seeking

In addition to the difficulty in controlling the vector, mining is illegal and is carried out in areas of difficult access, making timely diagnosis and treatment considerably difficult (22). Another problem in mining areas is that people infected with malaria often self-medicate with erratic regimens, often using just a dose called 'incubator' to quickly eliminate symptoms and return to mining (25, 26). These non-curative underdoses favour parasites resistant to anti-malarials. In addition, miners use drugs of dubious quality, such as Artecom® (artemisinin-based medication), which is not registered by a drug regulatory authority or by the WHO prequalified programme and is therefore illegal in French Guiana and neighbouring countries (26).

Behavioral factors significantly influence healthcare-seeking behaviors among miners, which in turn affect the risk of malaria transmission (27). Key behavioral factors include perceived risk and susceptibility, where miners with a higher perceived risk of malaria are more likely to seek care and get tested, reducing the risk of transmission (25). Additionally, higher levels of malaria knowledge among miners are associated with better care-seeking behaviors (25, 28). For instance, miners with high malaria knowledge were more likely to seek prompt care and get tested, which reduces the risk of malaria transmission (29).

Self-efficacy also plays a crucial role; miners who believe they can effectively manage their health are more likely to seek medical care (30). A study in Guyana found that miners with high self-efficacy were more likely to seek care for fever, reducing the risk of malaria transmission. Norms and beliefs about malaria and its treatment influence care-seeking behaviors as well. For example, miners who believe that mosquito net use is the norm in their camp are more likely to use them, which reduces the risk of malaria transmission (31). The knowledge, attitudes, and practices (KAP) regarding malaria transmission in mining areas are critical factors influencing the risk of malaria transmission among miners (25, 32, 33). Studies have shown that miners often have limited knowledge about malaria, which can lead to inadequate

preventive measures and delayed treatment. For instance, a KAP survey in Suriname found that gold miners had limited knowledge about malaria, which affected their practices and attitudes towards prevention and treatment (32). Similarly, in Western Kenya highlands, a study revealed that despite high awareness of malaria, there was a significant gap in the implementation of control practices, such as bed net use and environmental management, which are crucial for preventing malaria transmission. Attitudes towards malaria also play a significant role; miners who perceive malaria as a serious health risk are more likely to adopt preventive measures (34).

However, socio-economic factors, such as poverty and lack of access to healthcare services, can hinder the adoption of recommended practices. For example, in South Cameroon, the equatorial forest region, communities have shown awareness of malaria risks but lack the resources to implement effective control measures. Practices such as the use of insecticide-treated bed nets and environmental management (e.g., draining stagnant water) are essential for preventing malaria transmission. However, these practices are often not consistently implemented. In South Sumatra, Indonesia, studies have highlighted the importance of understanding the local vector dynamics and the impact of socio-economic factors on malaria transmission among miners (29). In summary, the KAP of miners regarding malaria transmission is influenced by a combination of knowledge gaps, socio-economic factors, and attitudes towards prevention and treatment (35). Targeted interventions aimed at improving knowledge, enhancing access to healthcare services, and promoting consistent preventive practices are essential for reducing the risk of malaria transmission in mining areas (36).

Access to services is another critical factor; proximity to testing services and a preference for public service treatment also play crucial roles (37). Miners who live closer to testing services and prefer public hospital services are more likely to seek testing and treatment, thereby reducing the risk of malaria transmission (25). Conversely, the practice of self-medication can be a barrier to seeking proper medical care. Miners who self-medicate are less likely to seek medical attention, which can increase the risk of malaria transmission (14). For example, a study in Guyana found that self-medication was lower among male miners, indicating that gender-specific interventions might be effective in reducing self-medication and improving care-seeking behaviors (25).

High-Mobility Individual

Human mobility is one of the reasons linked to the persistence or revival of malaria transmission, especially in cross-border situations and with the increasing anthropogenicization of natural ecosystems (2020). High malaria endemicity is a common feature of gold mining locations in the Guiana Shield, which includes French Guiana (FG), Suriname, Guyana, and the states of Venezuela, Colombia, and Brazil (38, 39). Since miners frequently travel across borders, they can support the reintroduction of malaria in low-burden areas (40).

Cross-border population movements in South America and Southeast Asia are a major obstacle to efforts to manage and eradicate malaria (41, 42). In this transborder context, a number of problems emerge, including delays in diagnosis and treatment, improper health-seeking behavior and self-medication, inadequate surveillance, and challenges in coordinating malaria monitoring and care between nations (21, 43). This makes it more difficult to avoid the reintroduction of malaria through border regions or migrant populations, which poses significant challenges for nations seeking to eradicate the disease or those who have previously done so (44, 45). One example of such a population is the extremely nomadic and frequently undocumented gold miners in the Amazon (46).

One prominent example of how mining zones contribute to the recurrence of malaria is Venezuela (47). All sectors of the nation are being negatively impacted by a catastrophic humanitarian catastrophe, and hyperinflation has reached an estimated 10 million percent. Emigration has increased significantly as a result of the economic unrest; between 2014 and 2019, 4.6 million people left the country. Many have relocated within, mostly to Bolivar state, which is home to 60–70% of Venezuela's malaria cases, and other illegal mining areas in the country's south. With the highest number of cases and fatalities, Venezuela is currently experiencing the greatest malaria pandemic of the twenty-first century in the Americas.

The result has been the largest malaria spillover in the Western Hemisphere, with cases of imported malaria from Venezuela rising in neighboring nations like Colombia, Guyana, Brazil, Suriname, Trinidad and Tobago, Chile, Argentina, Ecuador, and Peru (22). Another example, albeit with fewer participants, emphasizes how important it is to incorporate mobile populations into public health plans. Approximately 10,000 Brazilians without documentation from the states of Maranhão and Pará have moved to French Guiana to work in gold mines (32).

Environmental Changes

It is most likely the result of considerable environmental changes that impact vector abundance and transmission behavior that the high frequency of malaria in artisanal mining areas (ASM) (22, 26). ASM operations leave behind stagnant, contaminated water that attracts mosquitoes and spreads malaria (48). Our results indicate a strong correlation between malaria infection in these areas and recurrent episodes of malaria (49). We suspect that ASM and its related environmental circumstances, explaining the frequent malaria episodes in these study sites (50). Infections will continue until the mosquito breeding grounds that ASM left behind are located and managed (33, 51).

Open-pit mining has altered the surrounding ecosystem in native areas, leaving behind benches and hollows that serve as mosquito breeding grounds (26, 52). This is especially pertinent given that mining workers in these areas have a high malaria frequency (35). Pits that are filled with water and depressions are left behind during the lengthy excavation and removal of earth that occurs during open-pit mining (33, 53). These still pools of water provide the perfect environment for mosquitoes to develop, especially Anopheles species mosquitoes, which are known to spread malaria (54, 55).

Because they are so close to these reproductive grounds, mining workers in these locations are more likely to develop malaria (35). The risk of malaria transmission is exacerbated by the greater number of mosquitoes in and near mining sites (2). Miners are especially exposed to mosquito bites since they frequently work long hours and may live in temporary accommodation with little mosquito protection (56).

The relationship between malaria prevalence and environmental modifications resulting from mining operations emphasizes the necessity of focused malaria control strategies in these regions (2). Providing bed nets sprayed with pesticide to miners, cleaning or draining standing water to prevent mosquito breeding, conducting routine health examinations, and promptly treating malaria are all examples of effective tactics (4). The incidence of malaria among mining workers and the surrounding communities can be considerably decreased by addressing the environmental and occupational variables that contribute to the disease (2, 35).

CONCLUSION

Malaria transmission in mining areas, particularly in clandestine operations, is a significant public health concern. The unique combination of ecological disturbances, socio-economic factors, and behavioral practices among miners creates an environment conducive to malaria epidemics. High prevalence in area minings related to clandestine, which had mining activities and often occur in isolated areas with limited access to healthcare services, leading to inadequate preventive measures and delayed treatment. The mobility of miners, especially in regions with disturbed ecologies, facilitates the spread of malaria both within the mining areas and to surrounding communities. Additionally, the lack of education and knowledge about malaria transmission patterns, coupled with the promiscuous use of antimalarial drugs, exacerbates the problem. Interventions aimed at improving knowledge, enhancing access to healthcare services, and promoting consistent preventive practices are crucial for reducing the risk of malaria transmission in these high-risk settings.

SUGGESTION

The literature review on malaria transmission in mining areas highlights its primary focus on behavioural factors and environmental modifications, with little attention given to other sources such as water storage practices and contaminated water sources, as well as a lack of evaluation on the effectiveness of interventions in preventing malaria outbreaks. Additionally, the review tends to be biased towards specific geographical regions, overlooking regional variations, and fails to adequately address sociodemographic factors and the long-term impacts of malaria transmission. Therefore, a more comprehensive and holistic approach is needed in future research, encompassing broader sources of transmission, thorough evaluation of interventions, emphasis on regional differences, and careful consideration of sociodemographic factors and the long-term impacts of malaria transmission in mining areas.

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