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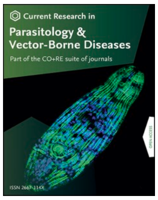

Occupational exposure to malaria, leishmaniasis and arbovirus vectors in endemic regions: A systematic review

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ABSTRACT

Vector-borne diseases, including dengue, leishmaniasis and malaria, may be more common among individuals whose occupations or behaviours bring them into frequent contact with these disease vectors outside of their homes. A systematic review was conducted to ascertain at-risk occupations and situations that put individuals at increased risk of exposure to these disease vectors in endemic regions and identify the most suitable interventions for each exposure. The review was conducted in accordance with PRISMA guidelines on articles published between 1945 and October 2021, searched in 16 online databases. The primary outcome was incidence or prevalence of dengue, leishmaniasis or malaria. The review excluded ecological and qualitative studies, abstracts only, letters, commentaries, reviews, and studies of laboratory-acquired infections. Studies were appraised, data extracted, and a descriptive analysis conducted. Bite interventions for each risk group were assessed. A total of 1170 articles were screened and 99 included. Malaria, leishmaniasis and dengue were presented in 47, 41 and 24 articles, respectively; some articles presented multiple conditions. The most represented populations were soldiers, 38% (43 of 112 studies); refugees and travellers, 15% (17) each; migrant workers, 12.5% (14); miners, 9% (10); farmers, 5% (6); rubber tappers and missionaries, 1.8% (2) each; and forest workers, 0.9% (1). Risk of exposure was categorised into round-the-clock or specific times of day/night dependent on occupation. Exposure to these vectors presents a critical and understudied concern for outdoor workers and mobile populations. When devising interventions to provide round-the-clock vector bite protection, two populations are considered. First, mobile populations, characterized by their high mobility, may find potential benefits in insecticide-treated clothing, though more research and optimization are essential. Treated clothing offers personal vector protection and holds promise for economically disadvantaged individuals, especially when enabling them to self-treat their clothing to repel vectors. Secondly, semi-permanent and permanent settlement populations can receive a combination of interventions that offer both personal and community protection, including spatial repellents, suitable for extended stays. Existing research is heavily biased towards tourism and the military, diverting attention and resources from vulnerable populations where these interventions are most required like refugee populations as well as those residing in sub-Saharan Africa.

1. Introduction

Vector-borne diseases, notably arboviral diseases, leishmaniasis and malaria, continue to disrupt everyday lives in endemic regions. These diseases cause substantial work absenteeism, increase morbidity and reduce productivity, with a substantial economic impact (Orem et al., 2012; Kioko, 2013; Lukwa et al., 2019). People may be exposed to vector bites at various times or locations depending on their daily activities (Monroe et al., 2019a). Some are temporarily exposed, while others are regularly exposed while working (Cotter et al., 2013). Those who work outdoors in disease-endemic areas may be simultaneously exposed to multiple disease vectors, including vectors of malaria, dengue or

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leishmaniasis (van den Bogaart et al., 2012; Aschale et al., 2019; Ahmed et al., 2021). All exposed to these vectors require vector bite protection that suits how, when and where they are exposed. Designing suitable interventions for such groups necessitates understanding the most vulnerable groups in endemic regions and the times and locations where populations are most likely to encounter vectors (Sturrock et al., 2013).

The most prevalent vector-borne diseases impacting people at work are dengue, leishmaniasis and malaria (GBD 2015 DALYs & HALE Collaborators, 2016). Lymphatic filariasis is also a prevalent vector-borne disease (GBD 2015 DALYs & HALE Collaborators, 2016) but is best controlled through preventative chemotherapy (Rebollo and Bockarie, 2017). Malaria, dengue and leishmaniasis pose a health threat to individuals in the tropics and subtropics who are refugees, are non-immune travellers, or spend most of their work time outdoors in endemic regions, including the military. These diseases place a heavy economic burden on not only individuals who get sick, but also those who care for the sick, their dependents, health care providers, businesses that rely on outdoor employment, and individuals who expect direct or indirect revenue from outdoor employment (Okwor and Uzonna, 2016; Castro et al., 2017; Conteh et al., 2021).

The distribution of dengue, malaria and leishmaniasis varies across occupations and outdoor activities. This review focuses on occupations associated with exposure to vectors resulting in higher frequency of infection and disease.

1.1. Dengue

Dengue is the most widespread arboviral (insect-transmitted virus) disease in humans (GBD 2015 DALYs & HALE Collaborators, 2016). The frequency and magnitude of dengue epidemics have increased dramatically in the past 40 years as both mosquito vectors and the four dengue virus serotypes have expanded geographically throughout the tropics and subtropics (Messina et al., 2019; Nature Education, 2014). The four dengue virus serotypes, DENV-1, DENV-2, DENV-3 and DENV-4, belong to the genus *Flavivirus*, family *Flaviviridae* (Westaway and Blok, 1997). Persons infected with one of these viruses acquire life-long immunity to that virus serotype but no cross-protective immunity to the other serotypes. Individuals living in dengue-endemic areas can be infected with all four dengue serotypes in their lifetime (Gubler, 1988). Risks posed by repeat dengue fever (DF) are much greater than those posed by the initial illness because the memory cells offer defence against reinfection only with the dengue serotype that caused the first illness (Sangkawibha et al., 1984; Wilken and Rimmelzwaan, 2020). The initial infection's antibodies contribute to the transmission of the dengue virus and raise viremia when a person contracts a second dengue serotype. The immune system responds by making antibodies to the previous strain, allowing the new strain to proliferate. Consequently, higher viral titres are reached, worsening clinical symptoms and prognosis, including dengue haemorrhagic fever (Halstead, 2002). The global resurgence of dengue is attributed to urbanisation, transportation, human movement changes and behaviour (Brady and Hay, 2020).

Several vectors can transmit dengue, but the primary vectors are *Aedes aegypti* and *Aedes albopictus* (Gubler, 1998a).

1.1.1. Dengue vector biology and behaviour: Aedes aegypti

Aedes aegypti is the primary vector of dengue (Ramchurn et al., 2009), and all four dengue serotypes have been isolated from field-collected specimens (Gratz, 2004). This mosquito species transmits other arboviruses, including yellow fever, chikungunya, and Zika viruses (Leta et al., 2018; Powell, 2018), and might be a vector of Venezuelan equine encephalitis virus (Powell, 2018). *Aedes aegypti* is widely distributed: in the tropics and subtropics of Africa, Asia, South America, the Mediterranean region and some parts of the Middle East. The origin of the species is suggested to be in Africa (Mattingly, 1957).

Globalisation has been a factor in the successful spread of *Ae. aegypti*. The species thrives in densely populated areas without reliable water supplies or proper waste management and with poor sanitation (Honorio et al., 2009). Historically, *Ae. aegypti* has moved from continent to continent *via* ships, and this method of dispersal is thought to present the highest risk of introduction (Weaver and Reisen, 2010). *Aedes aegypti* lives in close association with humans, feeding solely on human blood in the daytime and living and breeding around human homes (Powell and Tabachnick, 2013). The mosquitoes often rest in dark rooms (e.g. inside bathrooms and under beds) (Waldetensai et al., 2021; Janaki et al., 2022) and breed in small water pools that collect in discarded refuse or water storage containers (Day, 2016; Msellemu et al., 2020). Their eggs survive desiccation, which helps maintain vector survival throughout the year (Carvalho and Moreira, 2017). When an *Ae. aegypti* female carries dengue, the virus can be passed to eggs and hatched larvae may carry the virus (vertical transmission); therefore, the hatched larvae carry the virus (Buckner et al., 2013; Ferreira-de-Lima and Lima-Camara, 2018).

1.1.2. Dengue vector biology and behaviour: Aedes albopictus

Aedes albopictus, also known as the Asian tiger mosquito, is among the world's most invasive vector species because of its high ecological and physiological plasticity, including multiple breeding habitat types, drought-resistant eggs and adaptation to cold (Benelli et al., 2020). *Aedes albopictus* is competent for several arboviruses, including all four serotypes of dengue (Gratz, 2004), chikungunya and West Nile virus (Benedict et al., 2007; Muja-Bajraktari et al., 2022).

Aedes albopictus is an aggressive daytime biter (Benedict et al., 2007), and despite being an opportunistic feeder on a wide range of animal hosts, it prefers human blood (Benedict et al., 2007; Paupy et al., 2009). This opportunistic behaviour poses a serious health threat as the mosquito serves as a carrier, transmitting zoonotic infections to humans (Benedict et al., 2007). Although there are indications that *Ae. albopictus* is becoming partially endophilic (Genchi et al., 2009), it prefers to feed outdoors and is responsible for some recent disease outbreaks (Ramchurn et al., 2009; Rezza, 2012). It originated in Asia but has spread worldwide (Battaglia et al., 2022), and it will probably continue to spread until it has reached most of the tropics and subtropics and possibly also warmer temperate areas (Kraemer et al., 2019).

1.2. Leishmaniasis

Leishmaniasis comprises three protozoan parasitic diseases found in parts of the tropics, the subtropics and southern Europe and transmitted to humans by the bite of phlebotomine sand flies of the genus *Phlebotomus* or *Lutzomya* (Vega-Lopez and Ritchie, 2014; CDC, 2020a; WHO, 2022c). Three main forms of leishmaniasis infect people: cutaneous, visceral and mucocutaneous (WHO, 2022c). Cutaneous leishmaniasis is the most common; it causes skin lesions and ulcers on exposed parts of the body, leaving life-long scars and serious disability or stigma. Visceral leishmaniasis, also known as kala-azar, is the most serious form, leading to irregular episodes of fever, weight loss, enlargement of the spleen and liver, and anaemia (WHO, 2013a). Mucocutaneous leishmaniasis is severely disfiguring; it can lead to partial or total destruction of mucous membranes of the nose, mouth and throat (WHO, 2022c). Various species of an obligate intracellular parasite of the genus *Leishmania* are responsible for the disease (Akhoundi et al., 2016). This parasite dwells in cells of the monocytic phagocytic system of mammals and is transmitted by female sand flies (Steverding, 2017). More than 20 species of *Leishmania* are pathogenic to humans, and more than 30 species of sand flies function as vectors (Karimkhani et al., 2016) (Table 1). Akhoundi et al. (2016) provide a detailed review.

Globally, leishmaniasis has more than doubled in prevalence, from 1,934,553 cases in 1990 to 4,166,621 in 2017; 0.9–1.6 million new cases occur each year (GBD 2015 DALYs & HALE Collaborators, 2016). The recent influx of refugees may have contributed to the rise. Leishmaniasis is among the top ten neglected tropical diseases in the world and the second most common vector-borne parasitic disease infecting

Table 1
Manifestation and geographical distribution of leishmaniasis types. Only incriminated vectors are included, but there are numerous suspected vectors.

Leishmaniasis type	Manifestation	Pathogen	Sand fly vector species	Endemicity
Cutaneous (the most common form of leishmaniasis)	Infections appear like any other skin lesion.	Old World: *Leishmania major*; ***L. tropica***; *L. aethiopica*; ***L. infantum***; ***L. donovani*** (CDC, 2020a) New World: *L. mexicana*; *L. amazonensis*; *L. venezuelensis*; ***L. infantum*** (syn. *L. chagasi*)	Old World: *Phlebotomus alexandri*; *Ph. arabicus*; ***Ph. argentipes***; *Ph. longipes*; *Ph. martini*; *Ph. orientalis*; ***Ph. papatasi***[a]; *Ph. pedifer*; ***Ph. sergenti***[a] New World: *Lutzomyia anglesi*; ***Lu. longipalpis***; *Lu. flaviscutella*; *Lu. nuneztovari*; ***Lu. ovallesi***; *Lutzomyia* group Olmeca	Cutaneous infections are common in Afghanistan, Brazil, Iran, Peru, Saudi Arabia and Syria (Rahman et al., 2014); 90% of cutaneous leishmaniasis cases occur in Afghanistan, Brazil, Iran, Peru, Saudi Arabia and Syria (Soong, 2009).
Visceral (usually affects internal organs; also called kala-azar)	Fever, swelling of the liver and spleen, and anaemia. Fatality rate of 100% if not treated within two years (WHO, 2013a).	Old World: ***L. donovani***; ***L. infantum*** New World: ***L. infantum*** (syn. *L. chagasi*) (CDC, 2020a)	Old World: ***P. ariasi***; ***P. argentipes***; *P. orientalis*; ***P. perniciosus***; *Lu. cruzi*; *Lu. evansi*; ***Lu. longipalpis***	About 90% of cases occur in Bangladesh, Brazil, India, Nepal and Sudan (Thornton et al., 2010). Often transmitted in a peridomestic cycle in both the Old World (Bern et al., 2010; Rijal et al., 2019) and the New World (Sousa-Paula et al., 2020).
Mucocutaneous (*Leishmania* parasites may spread from the skin and cause sores in the mucous membranes of the nose).	Infection starts as a reaction at the bitten site and spreads into the mucous membrane; usually life-threatening.	*L. infantum* (syn. *L. chagasi*); *L. braziliensis*; *L.* (*Viannia*) *panamensis*; *L.* (*V.*) *guyanensis*; *L.* (*Leishmania*) *amazonensis* (CDC, 2020a)	*Lu. wellcomei; Lu. carrerai; Lu. complexa; Lu. fischeri; Lu. gomezi; Lu. neivai; Lu. nuneztovari anglesi; Lu. ovallesi; Lu. panamensis; Lu. shawi; Lu. spinicrassa; Lu. whitmani; Lu. ylephiletor; Lu. yucumensis*	About 90% of cases occur in Bolivia, Brazil and Peru (Casalle et al., 2020). It is almost always transmitted in a sylvatic transmission cycle.

Note: Bold typeface indicates involvement in anthroponotic and peridomestic transmission.

[a] Important in Syria.

individuals worldwide after malaria and is the third most common cause of morbidity after malaria and schistosomiasis in terms of disability-adjusted life years (DALYs) (GBD 2015 DALYs & HALE Collaborators, 2016). It is responsible for 20,000–30,000 deaths annually, and 350 million people at risk of infection, mostly in impoverished rural areas (Alvar et al., 2012; Mansueto et al., 2014; PAHO, 2017; Hotez, 2018). Leishmaniasis has a huge impact on affected countries, challenging public health services (Bacon et al., 2013), exacerbating poverty and decreasing worker productivity (Hotez et al., 2012). A large psychological burden results from disfiguration by skin lesions, and treatment is long and expensive (Sunyoto et al., 2019). In Nepal, the economic burden of leishmaniasis, including both direct and indirect costs, has been estimated at 11% of annual household income (Uranw et al., 2013).

1.2.1. *Leishmaniasis vector biology*

Phlebotomine sand flies are hematophagous insects and the natural vectors of leishmaniasis, *Bartonella* bacteria, sand-fly fever, and other bacterial and viral phlebovirus diseases (Maroli et al., 2013; Pons et al., 2016; Cecilio et al., 2022). About 50 species of *Phlebotomus* have been identified as potential leishmaniasis vectors (Kasap et al., 2013; Maroli et al., 2013; Medlock et al., 2014; Ayhan and Charrel, 2017). The vector lives in a variety of environments, from South American jungles to Middle Eastern deserts and on the Indian subcontinent. Sand flies are primarily active during dawn and dusk (CDC, 2020c; Durrani et al., 2012). They are primarily outdoor biters and very small, about one-fourth the size of mosquitoes (CDC, 2020a). They make no noise and have relatively painless bites (CDC, 2020c); thus, it is possible to be bitten by them unknowingly. Means for controlling the disease are situation-dependent (Balaska et al., 2021). Transmission can be classified broadly as sylvatic, for which personal bite protection tools are essential, and peridomestic (in and around human habitation), for which insecticides may be appropriate for control. Interventions include indoor residual spraying and the use of insecticide-treated nets for endophilic and anthroponotic sand flies (WHO, 2022d), and the use of deltamethrin-treated dog collars such as in Brazil to prevent zoonic transmission (Silva et al., 2019; Alves et al., 2020).

1.3. *Malaria*

Malaria is a parasitic disease caused by the coccidian protozoan of the genus *Plasmodium* and transmitted to humans by the bite of an infected female mosquito of the genus *Anopheles*, with about 70 species transmitting the disease (Sinka et al., 2012). *Plasmodium falciparum* is primarily responsible for severe illness in humans; *Plasmodium vivax* and, to a lesser degree, *Plasmodium malariae* and *Plasmodium ovale* also cause disease (Bruce-Chwatt, 1984). Parasite development is weather-dependent. Temperature is particularly critical; below 20°C (68 °F), *P. falciparum* cannot complete its growth cycle in the *Anopheles* mosquito and thus cannot be transmitted (CDC, 2020b).

Therefore, autochthonous malaria is most prevalent in the tropical regions causing high morbidity and mortality (GBD 2015 DALYs & HALE Collaborators, 2016). Nearly half the world's population lives in areas at risk of malaria transmission, in 87 countries and territories. Approximately 249 million clinical episodes and 608,000 deaths were attributed to malaria in 2022, i.e. 8 million deaths increase over 2021 (WHO, 2023a) Most malaria transmission (95%) and deaths (95%) occur in the WHO African Region, with four African countries accounting for just over half of all malaria deaths worldwide (WHO, 2021a). Malaria exerts a high economic and social burden on endemic countries (Sachs and Malaney, 2002); even after substantial control, a 10% reduction in malaria case incidence is associated with a 1.8% increase in gross domestic product per capita (Sarma et al., 2019). The greatest impact on households is lost productivity (Devine et al., 2019).

Malaria in sub-Saharan Africa is mainly controlled using insecticide-treated nets (ITNs) and indoor residual spray (IRS) (WHO, 2021a) because of the indoor biting and resting behaviour of Afrotropical malaria vectors (Sinka et al., 2010a). Personal protection using topical repellents and insecticide-treated clothing (ITC) is recommended for bite prevention where outdoor biting and resting occur (Sinka et al., 2010b, 2011), although there is insufficient epidemiological evidence to recommend these interventions for public health (Maia et al., 2018a).

1.3.1. *Malaria vector biology*

The habitat for the aquatic stage in the life-cycle of *Anopheles* mosquitoes varies, ranging from small puddles to the edges of large permanent water bodies, depending on the species. Many species have adapted to breed in man-made habitats such as rice fields or wells (Sinka et al., 2010a, 2011). In sub-Saharan Africa, four species of mosquitoes (*Anopheles gambiae* (*s.s.*), *Anopheles arabiensis*, *Anopheles funestus* and *Anopheles coluzzi*) mediate 95% of global malaria (WHO, 2021a). These species have co-evolved with humans to be synanthropic (they tend to be found biting in and around human homes and feed almost exclusively on humans) (Sinka et al., 2010a). Most malaria vectors bite throughout the night, with some peaks past midnight (Dambach et al., 2018; Bedasso et al., 2022). Malaria in Central and South America is dominated by *Anopheles albimanus*, found mainly along the Atlantic and Pacific coasts of Central America, Venezuela, Colombia, Ecuador, Peru and the Caribbean, and by *Anopheles pseudopunctipennis*, which is also found in the Andes in Bolivia, at higher altitudes than other malaria vectors (Sinka et al., 2010b). *Anopheles aquasalis* is found in brackish coastal habitats throughout Central America and the Caribbean and in South America down to Ecuador on the Pacific coast and northern Argentina on the Atlantic coast. Malaria throughout the Amazon is mediated by *Anopheles darlingi* in the forest, as well as by *Anopheles nuneztovari* (*s.s*) in the north and the *Anopheles albitarsis* complex in disturbed forest or agricultural areas (Sinka et al., 2010b). These vectors tend to bite and rest outdoors and have varying degrees of anthropophagy depending on the ecology of the location, although *An. darlingi* is the most anthropophagic and tends to bite throughout the night with a peak biting activity in the evening (Zimmerman et al., 2013).

In Southeast Asia, there is a similar focus of forest malaria in the Mekong sub-region, mediated by *Anpopheles dirus*, *Anopheles minimus* and *Anopheles maculatus* complexes, with other species dominating in rice fields, such as *Anopheles sinensis* and *Anopheles culicifacies* (Sinka et al., 2011). These vectors bite humans and other animals (Sinka et al., 2011). In the urban settings of India, the Middle East and the Horn of Africa countries, *Anopheles stephensi* breeding mainly in contained waters, is an important vector of malaria. *Anopheles fluviatilis* is a major malaria vector in hill forests in India. In Papua New Guinea and Australasia, members of the *Anopheles punctulatus* complex mediate malaria. These species, especially *Anopheles punctulatus*, *Anopheles koliensis* and *Anopheles farauti*, are generally synanthropic and preferentially feed on humans, although they will feed on other hosts (Sinka et al., 2011). These mosquitoes bite through the night with a peak in the evening.

The aim of this review is to identify the different occupational risks of vector-borne disease propose appropriate intervention for populations at higher risk of exposure to vectors of dengue, leishmaniasis and malaria; identify knowledge gaps; and establish an evidence base for best-practice guidance.

2. Materials and methods

The methods for this systematic review were developed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2009) (also see PRISMA checklist in Supplementary Table S1). The participants, interventions, comparators and outcomes (PICO) of the study are based on the Joanna Briggs Institute (JBI) protocol mnemonic “condition context, population” (CoCoPop) used in investigating the prevalence and incidence for systematic reviews (Munn et al., 2015). This review investigates vector-borne infections of dengue, leishmaniasis and malaria (condition) among outdoor workers, travellers and soldiers (population) who may be daily exposed to vector bites while fulfilling their day-to-day obligations in infection-endemic regions (context).

2.1. Definitions of outdoor occupations included in the review

2.1.1. Forest workers

Forest workers are those who conduct their work or other activities in and around forests. This category includes forest rangers, researchers, hunters, farmers and loggers who may enter and leave the forest daily or stay in it for some time. Because of the relatively low economic importance of forest work and its impact being largely on local populations, this occupation receives relatively little public health attention. Most forest workers are men aged 15–40 years (Davis et al., 2023), but may also include women (Östlund et al., 2020) and children.

2.1.2. Migrants

Migrants are persons who temporarily relocate to and live outside of their country or area of origin for economic reasons. Migrants are frequently involved in crop planting and harvesting, casual labour, construction and unskilled manual labour. They are primarily men, and often aged 15–40 years. Migrant workers may live in poor-quality accommodation, or their occupation may increase their exposure to disease vectors. Mobile migrant workers often lack immunity to locally circulating pathogens and may disseminate disease to new areas when they go home or to a different work location.

2.1.3. Deployed troops

Deployed troops are highly vulnerable to outdoor disease vectors because they are often deployed from another area and consequently lack immunity to locally circulating pathogens and spend much or all of their time outdoors. They include soldiers in active combat or training, security guards and sentries.

2.1.4. Refugees

A refugee is a person who “owing to a well-founded fear of being persecuted for reasons of race, religion, tribe, nationality, membership of a particular social group or political opinion, is outside the country of his nationality, and is unable to, or owing to such fear, is unwilling to avail himself of the protection of that country” (United Nations, 1989). There were about 27.1 million refugees and 53.2 million internally displaced people as of the end of 2022 (UNHCR, 2022a). Most refugees reside in the Middle East, South Asia or Africa. Two-thirds worldwide originate from the Syrian Arab Republic, Venezuela, Afghanistan, South Sudan and Myanmar, and 3 million Ethiopians are currently internally displaced (UNHCR, 2023). Not surprisingly, the overwhelming majority of refugees are hosted in neighbouring countries: Turkey, Lebanon and Jordan for Syrian refugees; Colombia for Venezuelans; Pakistan and the Islamic Republic of Iran for Afghans; Bangladesh and Malaysia for refugees from Myanmar; and Sudan, Ethiopia and Kenya for South Sudanese refugees (Devictor and Do, 2016; UNHCR, 2022a). Refugees and other displaced people are often more vulnerable to vector-borne disease because of poverty, poor living conditions and low immunity (Duffy et al., 1990; Boussery et al., 2001). The return of refugees or other displaced people to their homes also contributes to the spread of vector-borne disease (Sutherst, 2004; Abdul-Ghani et al., 2019).

2.1.5. Miners

Miners are people involved in the mining of metals and minerals such as gold, diamond and coal. Mining is commonly associated with vector bite exposure. Mining can be legal or unlawful, and its environmental disruption often increases the availability of breeding sites for vectors (Jones et al., 2018; Lowe, 2018). Miners comprise mobile populations of young adult men who often lack pre-existing immunity to locally circulating diseases. Miners may engage in shift work or open mining that exposes them to vector bites. They rarely come into contact with *Aedes* mosquitoes, which are more common in urban settings. Health problems occur because much informal mining activity is illegal and occurs in isolated areas without access to health services (Shanks and Wongsrichanalai, 2021). For miners, the risk of malaria is persistent, and the disease accompanies them as they move from one job site to another across many geographical areas, causing re-introduction of the disease (Cohen et al., 2012). Unfortunately, the problem is unresolved because health care systems struggle to reach miners working illegally in remote areas (Douine et al., 2017; Martins-Filho et al., 2023).

2.1.6. Tourists

It is predicted that by 2030 approximately 2 billion tourist trips to foreign countries will be taken worldwide each year (Paquet et al., 2022). Tourists are persons who travel for leisure or other purposes and stay in a country for 24 hours to 12 months. Travellers are vulnerable to vector bites and illnesses from vector-transmitted infections because most do not have immunity to diseases circulating in the host country. It has been estimated that 1.6 billion people travelled in 2020, with most of the trips in the tropics. Such a massive movement of people facilitates the spread of new and emerging infectious diseases (Odolini et al., 2012). The type of traveller may determine immediate or eventual infection outcome. Travellers who adopt local living standards can face a higher risk of endemic infection; these include individuals visiting friends and relatives and long-term expatriates (e.g. missionaries and business travellers). Others at higher risk are travellers staying in budget accommodation (e.g. local homes or hotels without screened windows) or camping. All long-term travellers have an inherently increased risk of infections because of prolonged exposure (Wu, 2019).

2.2. *Article selection and inclusion criteria*

Articles were selected by title. Abstracts of eligible papers were screened for inclusion and exclusion criteria (Table 2), and those meeting the criteria went on to full-text article review by one reviewer (DM). The review considered seasonal variance for at least one year because vector abundance and virus transmission vary seasonally. Dengue and malaria vectors are more prevalent during the rainy season (WHO, 2019a; Zheng et al., 2020), whereas sand flies are often abundant during the driest and/or coldest seasons of the year (Armed Forces Pest Management Board, 2015). Studies completed in less than a year may over- or underestimate infection in the region depending on season and vector abundance. If all criteria were met, data were extracted. EndNote reference manager software was used to store selected articles and remove duplicates.

The CoCoPop was used to define the inclusion criteria (Table 2) of the articles in this review. For a study to be included in the review, it had to meet all five criteria, i.e. condition, context, population, exposure type and study design.

2.3. *Conditions and outcomes*

Articles about the prevalence and incidence of malaria, dengue and leishmaniasis infections among risk groups with infection confirmed by laboratory tests (Table 3) were included in the review. The outcomes of interest were the incidence or prevalence of dengue, leishmaniasis or malaria infection or co-infection. We extracted estimates of dengue leishmaniasis and malaria prevalence and/or incidence according to how they were presented in the included studies. Prevalence was presented as a proportion or percentage, whereas incidence was presented in proportions and rates. Where prevalence was not directly indicated, percentage was computed as $(n/N) \times 100$, where n is the number of individuals testing positive and N is the total number of individuals examined.

2.4. *Context, population and type of exposure*

Articles included reported leishmaniasis, dengue and malaria infection or diseases among individuals who work outdoors or other risk groups in endemic countries. Articles that reported reintroduction of these infections in countries once considered to have achieved elimination were also considered.

This systematic review was restricted to people with occupational or other high risk of exposure in regions endemic for malaria, dengue and leishmaniasis and people who were infected in an endemic region and developed clinical signs in a non-endemic country. This population includes refugees, soldiers in combat or training, forest officers and loggers, game officers, rice farmers, people with night-shift duties such as security personnel or nurses, rubber tappers, fishers and miners. The participants' age range, occupations or behaviour that exposes them to vector bites was recorded.

The review considered only exposure to bites of *Aedes* spp., *Anopheles* spp. and sand flies in natural environments, excluding laboratory exposures and mother-to-child transmission.

2.5. *Study design: Risk of bias*

Investigator DM used criteria developed by Loney et al. (1998) modified to assess each article for risk of bias (Supplementary Table S2). For each of nine equally weighted questions, a "yes" response was worth one point, while any other reply ("no," "unclear" or "not applicable") scored zero. A score of 8–9 was categorised as low risk of bias and a high-quality article; a score of 6–7 was categorised as moderate risk and medium quality; and a score of 5 or below was categorised as high risk and low quality. Articles with fewer than 5 points were excluded.

2.6. *Literature search*

The review focused on articles published between 1945 and 2020 (Supplementary Table S3). No language restrictions were applied. Reference lists of all identified studies and review articles from relevant references not identified by the electronic search were also explored. Experts in the field were contacted for information about ongoing or unpublished studies.

Electronic databases searched were BIOSIS, Cochrane Central, Elsevier, Embase, Global Health, Google Scholar, JSTOR, LILACS, Medicine Plus, MEDLINE, OpenGrey, Oxford University Research Archive (ORA), PubMed, the U.S. National Library of Medicine, Web of Science, and WHO Search.

The search terms used were (malaria OR dengue OR leishmaniasis) AND (soldiers OR refugees OR tourists OR rubber tappers OR loggers) (Supplementary Table S3). To include articles that reported infection from non-endemic countries, the search strategy was not limited to countries or regions of endemicity of infection of interest. The strategy

Table 2
Inclusion and exclusion criteria used the CoCoPop criteria for extraction of relevant articles.

Category	Inclusion	Exclusion
Condition	Studies conducted in malaria-, dengue- and leishmaniasis-endemic regions, during disease outbreaks in non-endemic areas or in travellers returning from disease-endemic countries	Abstracts only, letters, commentaries, reports, and reviews
Context	Malaria, dengue and leishmaniasis acquired in endemic countries	Laboratory-acquired infection
Population	Military personnel, miners, forest workers, security personnel, open miners, gold miners in illegal operations, agriculture workers in forest-expanded areas, hunters, rubber tappers, humanitarian workers, outdoor recreation workers; religious gathering attendees; tourists returning from disease-endemic countries	Occupations/activities that do not expose individuals to outdoor biting vectors during the day or night
	Persons aged 18 years and above	Participants below 18 years of age
	Participants spending substantial time outdoors (exposed to vector by activities and occupations)	Laboratory- and other experimental environment-acquired disease
Diagnosis	Laboratory-confirmed diagnosis	Presumptive diagnosis
Study design	Conducted between 1945 and 2020	Conducted before 1945
	Observational	Ecological, qualitative
	Non-randomized controlled trials	Case series containing < 10 patients

Table 3
Confirmatory laboratory tests for diagnosis of dengue, leishmaniasis and malaria.

Test type		Dengue	Leishmaniasis	Malaria
General test category	Specific tests			
Virus detection/isolation	Vero and LLC-MK2	✔		
Genetic probe assays	Biotinylated probes			✔
	DNA hybridisation		✔	
	rRNA probes	✔		
RNA detection	Nucleic acid amplification test	✔		✔
	Nested PCR techniques	✔		✔
Antigen detection	NS1-based assays	✔		
	Immunohistochemistry	✔		
	Indirect fluorescence antibody test (IFAT)		✔	
	Ks30 dipstick test		✔	
Serological tests	Direct agglutination test		✔	
	ELISA	✔	✔	✔
	MAC-ELISA	✔		
	Protein G ELISA	✔		
	IgM-based assays	✔	✔	✔
	IgG-based assays	✔	✔	✔
	IgA-based assays	✔	✔	
	IgE-based assays	✔		
	Protein A (ProtA)		✔	
	Hemagglutination inhibition	✔		
	Immunofluorescence antibody testing		✔	✔
	Plasmodium lactate dehydrogenase (pLDH)			✔
	ELISA IgG2 and IgG1		✔	
	Lymphocyte proliferation assay		✔	
	LAMP		✔	
	Neutralisation test			
	Complement fixation			
Molecular methods	PCR			✔
	qPCR			✔
	qPCR-BM (bone marrow)		✔	
	qPCR-blood		✔	
	Microarrays			✔
	Flow cytometry assay			✔
	Automated blood cell counters			✔
	Mass spectrophotometry			✔
	Plasmodium-specific phospholipases A2			✔
Microscopy	Giemsa-stained blood film		✔	✔
	Fluorescent microscopy			
Rapid methods: Malaria antigen detection	Malaria rapid diagnostic test			✔
	Highly sensitive rapid diagnostic tests		✔	
	ParaHIT			✔
	Paracheck			✔
Quantitative buffy coat method	Becton Dickinson			✔
LAMP				✔
Immuno-chromatographic technique		✔		✔
ParaScreen				✔
SD Bioline				✔
Post-mortem diagnosis of malaria	Histopathology			✔
Diagnosis of malaria in pregnancy	Placental histology			✔
Complete blood count and chemistry profile				✔
Plasmodium lactate dehydrogenase assay	Immunochromatographic dipstick assay			✔
	Ks30 dipstick test		✔	
Skin testing	Montenegro; delayed-type hypersensitivity		✔	

Abbreviations: ELISA, enzyme-linked immunosorbent assay; IgG, immunoglobulin G; LAMP, loop-mediated isothermal amplification; MAC-ELISA, IgM antibody capture; PCR, polymerase chain reaction; qPCR, quantitative PCR.

succeeded in clearly identifying eligible studies (Wangroongsar et al., 2016; Douine et al., 2019; Arisco et al., 2021) from nine databases (Supplementary Table S4; the table indicates when each database was searched). Colleagues helped obtain 19 additional articles for the review.

2.7. Data extraction and effect measures

A custom Microsoft Excel spreadsheet was used to extract information from articles. In accordance with recommendations by Munn et al. (2020), the following data were extracted: condition, context (country of endemicity), population, study type, study duration, study year, incidence, prevalence, sample size (*N*), age range, diagnostic tool(s) and bibliographic reference. The data collection form was assessed and tested before data extraction began. Two reviewers worked independently. One extracted the data; the other checked and verified the collected data. When full articles were not available for data extraction, the author/investigator was contacted. Google Translator was used for articles in French, Portuguese and Turkish; no other non-English articles were obtained.

Effect measures extracted were incidence and prevalence. Incidence was presented as incidence rate or incidence rate ratio; prevalence was presented as prevalence proportions or obtained from presented odds ratios. No other effect measures were extracted.

2.8. Data synthesis

The review focused on assessing articles that presented prevalence and/or incidence of dengue, leishmaniasis and malaria infections. Data synthesis was of descriptive characteristics of the study and participants. Information collected was assessed based on the risk of disease to people whose occupations require them to spend most of their working hours outdoors in endemic regions of malaria, leishmaniasis and dengue.

3. Results

3.1. Study selection

The flow diagram (Fig. 1) presents the systematic approach used to select relevant articles throughout the research process, from the initial search, through various screening stages, to the final inclusion of 99 articles meeting the criteria for the study.

3.2. Populations presented

The 99 articles obtained (Fig. 1) describing 112 conditions are summarised in Table 4. Some articles presented more than one condition; other articles presented more than one population. The military population was the most represented, at 38% of conditions (43/112), followed by refugees, 15% (17/112); travellers, 15% (17/112); migrant workers, 12.5% (14/112); miners, 9% (10/112); farmers. 5% (6/112); rubber tappers and missionaries, 1.8% each (2/112); and forestry, with only 1 article. The word cloud in Fig. 2 presents the populations proportionally.

3.3. Continent of endemicity

By continent of endemicity, Asia had the largest share, at 38% of 112 studies (from 99 articles), followed by the Americas (Central and South), with 21%, Africa, with only 18% and Middle East with 16%. "Others" in Fig. 3 represents studies involving numerous centres or compiling and consolidating data on cases from multiple locations.

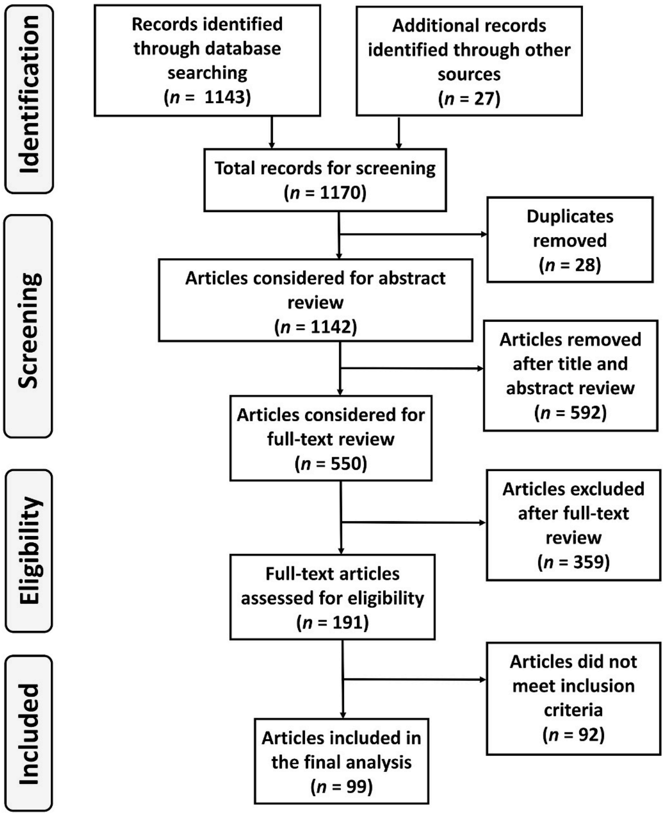

Fig. 1. PRISMA flow diagram.

3.4. Study quality

The risk of bias was assessed using the information in Supplementary Table S2. Only 14 (14%) of the 99 articles obtained earned 8 "yes" responses, showing a very low probability of bias.

Biases in the studies included: (i) sample size: 11% of studies did not report the sample size; (ii) diagnosis: 1% of studies failed to report the diagnostic tools used; (iii) age of participants: 38% of studies failed to report participants' ages; and (iv) study duration: 14% of studies had short study durations of less than one month; 23% had durations of more than one month but less than six months; and 12% had durations of more than six months but less than a year. Overall, 44% of the articles had the target duration of more than a year. Only five studies provided no information on the study duration. About 38% of the articles reviewed were from Asia.

3.5. Reporting biases

Malaria was most reported, and, unsurprisingly, the two neglected tropical diseases (NTDs) (leishmaniasis and dengue) were reported at a lower frequency. There were twice the number of articles about soldiers relative to other occupations (Fig. 3).

3.6. Disease and risk groups

3.6.1. Refugees

Although refugees were underrepresented in the literature, they make up a large risk group and often suffer high mortality from vector-borne diseases. Civil war and internal displacement of people in endemic countries contribute significantly to the spread of leishmaniasis. In Syria, a 10-fold increase to 270,000 cases of leishmaniasis occurred in 2016 (Hotez, 2018). The displacement of over 4.2 million Syrians into neighbouring Turkey, Lebanon and Jordan led to outbreaks of leishmaniasis where refugees and sand flies coexist (Koltas et al., 2014; Alhawarat et al., 2020; Ozbel et al., 2022). In Latin America, similarly, the incidence of leishmaniasis is far higher among internally displaced people (Villamizar-Pena et al., 2021). Armed conflict enables outbreaks of serious NTDs (Jacobson, 2011; Du et al., 2016) through a combination of factors, most notably, collapsed health-care infrastructure and population displacement. As populations migrate to endemic and non-endemic regions, they are exposed to infections for the first time or introduce diseases into new areas, respectively (Du et al., 2016).

Malaria is most commonly transmitted outdoors in forested tropical regions of South America (MacDonald and Mordecai, 2019) and Southeast Asia (Sandfort et al., 2020) and among refugee populations in sub-Saharan Africa (WHO, 2013b). One-third of global refugees are located in sub-Saharan Africa. At the same time, 90% of worldwide malaria-associated deaths occur in sub-Saharan Africa, about one-third taking place in complex humanitarian emergency settings; 18.7% of refugee deaths in 2021 were caused by malaria (UNHCR, 2022b). A major aspect of emergency settings is large-scale population displacement, often with a high proportion of children and women of child-bearing age, who are most at risk of malaria death (Amodu et al., 2020; Salami et al., 2020).

Refugees were noted to have dengue outbreaks in camps in areas with frequent dengue virus circulation, including among Rohingya refugees in Bangladesh (WHO, 2022a). Because of the destabilisation of public health in Yemen by war, dengue outbreaks have also been recorded (Alghazali et al., 2019). Alarmingly, as dengue becomes more common in Africa (Brady and Hay, 2020), outbreaks have been recorded among refugees in Sudan (Ahmed et al., 2021) and Somalia (Botros et al., 1989).

Refugees can also introduce infections to the host population, as recently occurred in Turkey with displaced Syrian populations (Salman

Table 4
Characteristics of included studies.

Condition/ Context	Population	Study type	Study duration	Study years	Incidence	Prevalence	*N*	Age range (years)	Diagnostic tools	Appraisal score	Reference
Dengue											
Africa	Soldiers	Prospective study	24 m	2011	330/25,458		25,458	19–56	ELISA, RT-PCR	7	de Laval et al. (2013)
Africa	Refugees	Active surveillance	3 m	2019	24% dengue fever; 54% dengue with warning signs; 22% severe dengue		–	1–81	RT-PCR	5	Ahmed et al. (2021)
Africa	Refugees	–	3 y	1997–2006	15/38		38	–	ELISA	5	Botros et al. (1989)
Africa	Soldiers	Retrospective study	36 m	2008–2011	17.6/10,000		1000	19–56	Serum, ELISA, microneutralisation assay	7	Hesse et al. (2017)
Africa	Soldiers	Prospective study	12 m	1992–1993	43% virus isolation; 35% IgM-reactive		129	19–25	Serum	6	Sharp et al. (1995)
Americas	Soldiers	Retrospective study	36 m	2008–2011	17.6/10,000		1000	19–56	Serum, ELISA, microneutralisation assay	7	Hesse et al. (2017)
Americas	Soldiers	Consecutive sample	2 m	1994	30/406		406	–	ELISA, virus isolation	6	Trofa et al. (1997)
Americas	Missionaries	Incidence	<1 m	2010		25%	28	16–69	RT-PCR, IgM, MAC-ELISA	5	CDC (2011)
Americas	Missionaries		0 m	2019		25%	28	11–69	rRT-PCR, MAC-ELISA	5	Sharp et al. (2012)
Asia	Travellers	Retrospective study	48 m	2001		5.6%	696	15–54	ELISA	5	Sung et al. (2003)
Asia	Migrants	Screening	<1 m	2003		IgG: 80%; IgM: 0.5%	600	20–39	IgM/IgG	6	Perng et al. (2019)
Middle East	Refugees	Incidence study	12 m	2016	27%		436	1–70	PCR	5	Alghazali et al. (2019)
Southeast Asia	Soldiers	Outbreak study	2 m	1984	24/1000		–	20–43	HI	5	Hayes et al. (1989)
Southeast Asia	Soldiers	Prospective cohort	5 m	2015		6.60%	585	–	NT	5	Peragallo et al. (2003)
Southeast Asia	Soldiers	Prospective cohort	4 m	2000		0.04%	2500		IgM & IgG	7	Kitchener et al. (2002)
Southeast Asia	Soldiers	Retrospective study	36 m	2008–2011	17.6/10,000		1000	19–56	Serum, ELISA, microneutralisation assay	7	Hesse et al. (2017)
Other	Soldiers	Prospective study	24 m	2011	330/25,458		25,458	19–56	ELISA, RT-PCR	7	de Laval et al. (2013)
Other	Travellers	Prospective study	10 y	2010	21/1000		24,920	–	Serum, ELISA	6	Schwartz et al. (2008)
Others	Travellers	Incidence	36 m	2005		0.34%	63,000	11–70	RT-PCR, IgG, IgM	7	Wichmann et al. (2007)
Other	Travellers	Incidence	70 m	2010		10.1%	594	40–49	ELISA, IgG, IgM	7	Allwinn (2011)
Other	Travellers	Retrospective study	120 m	2013		132 (21.5%)	614	40–49	NS1, RT-PCR	7	Trojanek et al. (2016)
Southeast Asia	Travellers	Retrospective study	0–16 m	1999	107/292		292	19–60	Indirect IFA	6	Lindback et al. (2003)
Southeast Asia	Travellers	Retrospective study	60 m	2010	Sri Lanka: 45.3/100,000; Bangladesh: 42.6/100,000; Thailand 13.6/100,000		925	0–76	NS1, PCR, IgM	7	Rocklov et al. (2014)
Southeast Asia	Travellers	Systematic records/ retrospective study	5 y	2005		13/100,000	211	–	Microscopy	6	Stienlauf et al. (2005)

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Table 4 (*continued*)

Condition/ Context	Population	Study type	Study duration	Study years	Incidence	Prevalence	*N*	Age range (years)	Diagnostic tools	Appraisal score	Reference
Southeast Asia	Migrant workers	Prospective study	2 m	2002	39/47 cases; 27/274 surveyed		47 & 274	–	ELISA	5	Seet et al. (2005)
Southeast Asia	Travellers	Prospective cohort	32 m	2017		62%	201	17–78	RT-PCR, NS1	7	Masyeni et al. (2018)
Leishmaniasis											
Africa	Farmers	Cross-sectional study	–	2014		38%	130	–	ZCL lesion	5	Bellali et al. (2017)
Africa	Migrants	Case-control studies	36 m	2011		39%	376	14–38	Positive DAT (*Leishmania* amastigotes)	8	Argaw et al. (2013)
Africa	Migrants	Cross-sectional study	3 m	2016		9.6%	178	1–29	ICT	8	Aschale et al. (2019)
Africa	Refugees	Outbreak study	–	–	24.1%		2714	–	ELIZA, DAT	5	de Beer et al. (1991)
Americas	Miners, migrants	Cross-sectional study	9 m (wet season)	2017/2018		73%	168	16–75	Smear, culture, PCR-RFLP	7	Loiseau et al. (2019)
Americas	Soldiers	Retrospective study	12 y	1978		61%	306	–	Culture	7	Hepburn et al. (1993)
Americas	Soldiers	Retrospective study	2 y	2011	1998: 29/990; 2004: 14/80		99 in 1998; 80 in 2004	18–48	Serum, culture	7	van Thiel et al. (2011)
Americas	Soldiers	Outbreak study	6 m	2020	3.5% (AR)		858	–	PCR	7	Henry et al. (2021)
Americas	Soldiers	Retrospective study	7 m	2004		237/360	360	–	Giemsa stain, PCR	6	Willard et al. (2005)
Americas	Soldiers	Outbreak study, Incidence study	6 m	Aug 2002–Jan 2003	16.9/100 (AR)		71	19–37	Microscopy, RDT	6	Berger et al. (2006)
Americas	Soldiers	Outbreak study	3 m	1996	Outbreak, 8 cases		8	–	Biopsy, smear, skin test	5	Silveira et al. (2002)
Americas	Soldiers	Outbreak study	1 m	1986	77/303 (AR)		303	18–23	Microscopy	7	Ore et al. (2015)
Americas	Soldiers	Not stated; suggests a prospective study	12 m	2002		25.3%	352	–	Montenegro skin test	6	Andrade et al. (2005)
Americas	Soldiers	Incidence study	3 m	1995	89.6%		48	19–20	Giemsa stain, Montenegro intradermal reaction	7	de Oliveira Guerra et al. (2003)
Americas	Soldiers	Prospective cohort	6 y	1981–1987	2.3/1000		–	15–56	Scar	7	Dedet et al. (1989)
Americas	Soldiers	Double-blind, placebo-controlled study	3 m	1995		2.8% active; 12.6% control	86	–	Microscopy, culture	6	Soto et al. (1995)
Asia	Soldiers	Prospective cross-sectional survey	12 m	1985		50/5000	5000	–	PCR, RDT, microscopy	7	Gunathilaka et al. (2020)
Asia	Refugees	Cross-sectional study	2 m	1998		2.70%	19,918	–	Microscopy	6	Kolaczinski et al. (2004)
Asia	Refugees	Cross-sectional study	1 m	1997		38%	799	0–80	Microscopy, culture, PCR	7	Rowland et al. (1999)
Asia	Refugees	Cross-sectional, multicentric and observational study	–	2015		8.3%	421	–	PCR	6	Douine et al. (2017)
Asia	Travellers	Retrospective study	168 m	2016		60% (182)	299	3–80	Microscopy, skin smears	8	Sobirk et al. (2018)
Middle East	Refugees	Retrospective study	3.5 y	Jan 2011–Jun 2014		110	110	1–78	Skin lesion	6	Inci et al. (2015)
Middle East	Refugees	Retrospective study	63 m	2020		20	–	3–33	Biopsy, PCR	5	Lindner et al. (2020)
Middle East	Refugees	Retrospective study	84 m	2016		92.1% imported cases	558	1–78	PCR	8	Amr et al. (2018)
Middle Easy	Refugees	Outbreak study	1 m	2012		74% of suspected cases	1275	–	Biopsy, PCR	5	Saroufim et al. (2014)

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Table 4 (*continued*)

Condition/ Context	Population	Study type	Study duration	Study years	Incidence	Prevalence	*N*	Age range (years)	Diagnostic tools	Appraisal score	Reference
Middle East	Refugees	Descriptive study	6 y	2010 & 2016	2.87/100,000 (IR)			–	Direct slit-skin smear	5	Kanani et al. (2019)
Middle East	Soldiers	Cross-sectional study	1 m	2013		13%	225	19–63	ELISA	8	Obwaller et al. (2018)
Middle East	Soldiers	Retrospective study	6 m	2003		1.18%	360	–	PCR, biopsy, Giemsa-stained lesion smear	5	Willard et al. (2005)
Middle East	Soldiers	Prospective cohort study	2 y	2015		19.5%; 64% bitten by sand fly	200	24–61	rK39, ELISA, IGRA, qPCR	7	Mody et al. (2019)
Middle East	Soldiers	–	–	2017		18%	247	–	ELISA, PCR, EDTA	5	Giladi et al. (1985)
Middle East	Refugees	Incidence study	3.5 y	2010	18.5%		416	0–60	Giemsa-stained smear	7	Salman et al. (2014)
Middle East	Travellers	Systematic records/ retrospective study	5 y	2005		9%	211	–	Microscopy	6	Stienlauf et al. (2005)
Other	Soldiers	Case series	132 m	2011		223 all cases	223	2–86	Giemsa stain, PCR	8	Wall et al. (2012)
Other	Soldiers	Cross-sectional study	1 m	1985		13.30%	225	19–63	ELISA	7	Obwaller et al. (2018)
Other	Travellers	Cross-sectional study	120 m	2008		64%	286	11–77	Smear biopsy, PCR	6	Solomon et al. (2011)
Other	Travellers	Case series	132 m	2011		223 nested cases	223	2–86	Giemsa stain, PCR	8	Wall et al. (2012)
Other	Travellers	Retrospective study	96 m	2003		79	–	19–30	Microscopy, PCR	5	Lawn et al. (2004)
Malaria											
Africa	Farmers	Cross-sectional study	1 m	2020		Microscopy: 14%; RDT: 17%	1154	1–51+	Microscopy	7	Mazigo et al. (2017)
Africa	Migrants	Cross-sectional study	3 m	2019		55%	773	27–52	RDT, PCR	7	Martins et al. (2020)
Africa	Migrants	Cross-sectional study	3 m	2016		22.4%	178	15–65	Microscopy	8	Aschale et al. (2019)
Africa	Migrants	Cross-sectional study	3 m	2019		55%	773	27–52	RDT, PCR	7	Martins et al. (2020)
Africa	Miners	Screening study	4 m	2014	216/1000 (AR)		4053		Microscopy, IFA	6	Li et al. (2015)
Africa	Soldiers	Retrospective study	20 y	2014	107/1000/year		101 in 2005	17–48	Biopsy	7	de Laval et al. (2014)
Africa	Soldiers	Prospective study	6 m	1996		43%	245	29–52	–	6	Ennibi et al. (2012)
Africa	Soldiers	Prospective cohort study	6 m	2015	1.8/10,000/week		389	–	RDT, microscopy	6	Wallace et al. (1996)
Africa	Soldiers	Outbreak study	6 m	2013	18% (AR)		439	–	IFA	5	Sanchez et al. (2000)
Africa	Soldiers	Incidence study	6 m	2002	71.3%		72	–	Smear or microscopy	6	Kawar et al. (2003)
Africa	Migrants	Cross-sectional study	0 m	2013		12% overall	592	18–65	RDT	7	Schicker et al. (2015)
Africa	Refugees	Community trial	5 m	Jan 2001–Dec 2012	OR 0.30 of treatment arm		198	–	PCR, microscopy	6	Kimani et al. (2006)
Americas	Migrants	Case series	–	2015		8/154	154	–	Microscopy	5	Carreno-Almanzar et al. (2021)
Americas	Migrants	Surveillance	11 y	2018		3%	–	< 5–65 >	Microscopy, RDT	7	Arisco et al. (2021)
Americas	Miners	Passive surveillance	12 y	2016		15%	203,773	–	Microscopy	7	Sanchez et al. (2017)
Americas	Miners	Case detection	5 d	2017	53.8% (AR)	60%	46	–	RDT	6	Douine et al. (2019)
Americas	Miners	Surveillance	11 y	2018		3%	–	<5–65>	Microscopy, RDT	7	Arisco et al. (2021)
Americas	Miners	Cross-sectional, multicentric, observational study	6 m	2020		22.3% (PCR prevalence)	421	–	NT	6	Douine et al. (2016)
Americas	Miners	Cross-sectional study	6 d	2006		19%	135	24–58	ELISA, IgG	6	Silbergeld et al. (2002)
Americas	Miners	Cross-sectional study	1 m	1996		48.3%	205	20–63	Blood testing/not mentioned	7	Pommier de Santi et al. (2016b)
Americas	Soldiers	Double-blind, placebo-controlled study	3 m	1995	17%		143	–	Microscopy, PCR	6	Soto et al. (1995)

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Table 4 (*continued*)

Condition/ Context	Population	Study type	Study duration	Study years	Incidence	Prevalence	*N*	Age range (years)	Diagnostic tools	Appraisal score	Reference
Asia	Farmers	Cross-sectional study	1 m	2016		0.27%	750	18–84	Microscopy, RDT	8	Wangchuk et al. (2019)
Asia	Farmers	Cross-sectional study	2 m	1996/1997		33.5%	842	–	Microscopy	6	Pluess et al. (2009)
Asia	Migrants	Cross-sectional study	5 m	2016		3.8%	309	27.70 ± 11.98	RDT	7	George et al. (2019)
Asia	Migrants	Cross-sectional study	1 m	2016		0.42%	473	18–66	Microscopy, RDT	8	Wangchuk et al. (2019)
Asia	Refugees	Cross-sectional, multicentric, observational study	–	2015		22.3%	421	–	RDT, PCR	6	Douine et al. (2017)
Asia	Refugees	Cross-sectional malariometric surveys	4 m	2016		Seroprevalence *P. vivax* (Jalala: 47.5%; Adezai: 17.6%); PCR *P. vivax* (Jalala: 15.6%; Kagan: 3.7%); *P. falciparum* (Jalala: 1.4%; Kagan: 0.8%)	2522	–	Blood sample	6	Wahid et al. (2016)
Asia	Soldiers	Prospective cohort study	12 m	1993–2007		21/246	246	–	Microscopy, PCR	7	Henderson et al. (1986)
Asia	Soldiers	Prospective cohort study	14 y	2015	Incidence 2.5/1000 in 1999		–	–	Microscopy	6	Klein et al. (2009)
Asia	Soldiers	Incidence study	8 m	2012		62%	–	20–42	Blood smear, RDT, PCR	6	Shaha et al. (2013)
Asia	Soldiers	Case series	4 m	2002	52.4/1000		752	19–39	Microscopy	8	Kotwal et al. (2005)
Southeast Asia	Soldiers	Cross-sectional study	1 m	2017		11.2%	313	24–40	RDT, microscopy	7	Vilay et al. (2019)
Southeast Asia	Soldiers	Prospective cohort study	12 m	1999	13% (AR); 5.2% (AR of redeployed)		–	–	Blood slide, PCR	6	Kitchener et al. (2003)
Asia	Soldiers	Prospective cohort study	8 m	2015		82%	11	–	BinaxNOW® malaria kit, PCR	5	Klein et al. (2018)
Asia	Soldiers in DMZ	Outbreak study	12 m	2010		70%	3932	21–24	Biopsy, PCR, microscopy, histology	8	Lee et al. (2002)
Other	Migrants	Retrospective study	240 m	2015		89.3%	3099	0–83	Microscopy	7	Wangdahl et al. (2019)
Other	Miners	Retrospective cohort study	4 m	Sep 2010–Jan 2011	Attack rate 26.5%		272	–	Blood smear, RDT, quantitative buffy coat	5	Pommier de Santi et al. (2016a)
Other	Travellers	Retrospective study	240 m	2015		89.3%	3099	0–83	Microscopy	7	Wangdahl et al. (2019)
Other	Travellers	Prospective cohort study	5 y	1985–1987	Burma: 11.80/100,000; Korea: 0.25/10,000		2653	–	Microscopy, RDT, PCR	7	Behrens et al. (2010)
Other	Soldiers	Epidemiological review	14 y	1999	0.03/person/year (AR)		213	–	Microscopy, serum	7	Miller et al. (1999)
Southeast Asia	Farmers	Cross-sectional study	2 m	2003		25%	4306	16–60	Microscopy	7	Erhart et al. (2005)
Southeast Asia	Farmers	Prospective study	12 m	2005	780 cases; no denominator	0.55–2.1%	780 cases	–	Microscopy	7	Singhasivanon et al. (1999)
Southeast Asia	Forestry	Experimental study	5 m	2003–2008	479/1000	30/150 (∼20%)	150	–	Microscopy	6	Son et al. (2017)
Southeast Asia	Soldiers	Experimental non-randomised study	5 m	2017	62%		118	–	Microscopy, PCR	5	Brown et al. (1990)
Southeast Asia	Rubber tappers	Incidence study	–	2018		2.3%	470	–	RDT, ELISA, PCR	6	Jeffree et al. (2018)

(*continued on next page*)

Table 4 (*continued*)

Condition/ Context	Population	Study type	Study duration	Study years	Incidence	Prevalence	*N*	Age range (years)	Diagnostic tools	Appraisal score	Reference
Southeast Asia	Rubber tappers	Incidence study	7 m	2000	IRR 2.9		33	-	IgM or IgG by ELISA or isolation of dengue virus	6	Pattanasin et al. (2012)
Southeast Asia	Refugees	Incidence study	3 y	1985	1983 (359/1000); 1984 (350/1000); 1985 (116/1000)		–	< 5–44	Blood smear	7	Meek (1988)
Middle East	Travellers	Systematic records/ retrospective study	5 y	2005		26%	211	–	Microscopy	6	Stienlauf et al. (2005)

Abbreviations: Study duration: d, days; m, months; y, years. Diagnostic tools: AR, attack rate; ARR, attack rate ratio; DAT, direct agglutination test; EDTA, ethylenediaminetetraacetic acid; ELISA, enzyme-linked immunosorbent assay; HI, hemagglutination inhibition; ICT, immuno-chromatographic technique; IFA, immunofluorescence antibody testing; IR, incidence rate; IRR, incident rater ratio; IgG, immunoglobulin G; IgM, immunoglobulin M; IGRA, interferon-gamma release assay; MAC-ELISA, IgM antibody capture ELISA; NS1, non-structural protein 1; NT, neutralisation test; OR, odds ratio; PCR, polymerase chain reaction; qPCR, quantitative PCR; RDT, rapid diagnostic test; RFLP, restriction fragment length polymorphism; rRT-PCR, real-time reverse transcription PCR; RT-PCR, reverse transcription PCR; ZCL, zoonotic cutaneous leishmaniasis.

Fig. 2. Word cloud of frequency of reported occupation or other risk groups (WordClouds.com).

et al., 2014; Inci et al., 2015). Refugees who arrive with an infection can also transmit the infection to non-infected refugees, resulting in outbreaks (Abdul-Ghani et al., 2019; Ahmed et al., 2021). Large-scale epidemics can arise if the refugees come from a non-immune background, and vector-borne illness can become endemic if competent vector populations are present in the region where refugees are housed. The current conflict in Syria has led to a 485% increase in vector-borne diseases, including leishmaniasis and malaria, in Syria and its neighbouring countries (Tarnas et al., 2021). The arrival of Afghan refugees in Pakistan resulted in an increase in the global malaria burden (Rowland et al., 2002). When Somali refugees arrived in Oman, a malaria epidemic occurred in a previously malaria-free area (Baomar and Mohamed, 2000).

Refugees' exposure is different when on the move and when they have reached a camp. Those in transit tend to sleep anywhere, keep moving during the day and night, and thus have round-the-clock exposure (Fig. 4). Those in camps have similar exposure to vectors as the host population, which may be during the evening or the night depending on local vectors, although transmission may be higher than among the host population and housing conditions are often of a low standard allowing vectors easier access to human hosts and making vector control more complicated (Messenger et al., 2023).

3.6.2. Soldiers

Deployed troops now face a greater risk from vector-borne infections because vectors and the diseases they carry have changed geographically, qualitatively and quantitatively throughout time (Zapor and Moran, 2005). During the first Gulf War, among the 40 cases of leishmaniasis in U.S. soldiers recorded from Iraq, 12 were visceral leishmaniasis because of an unexpectedly high frequency of *Leishmania tropica* vascularisation (Pages et al., 2010). The majority of leishmaniasis cases have been documented since the year 2000, with about 80% of travel-acquired leishmaniasis in soldiers who travelled to endemic countries (Pavli and Maltezou, 2010). Therefore, according to available reports, soldiers are among the most reported and researched vulnerable groups to suffer from leishmaniasis (Pavli and Maltezou, 2010), although the burden is higher among refugees who remain for prolonged periods of time in endemic areas (Du et al., 2016). From 1942 to 1945, among the 1000 cases of cutaneous leishmaniasis recorded by the U.S. Army in all theatres, 630 occurred within 3 months in a single outbreak in the Karun River Valley of Iraq (Tesh, 1989). Leishmaniasis has been regularly reported by European and U.S. armed forces in training or

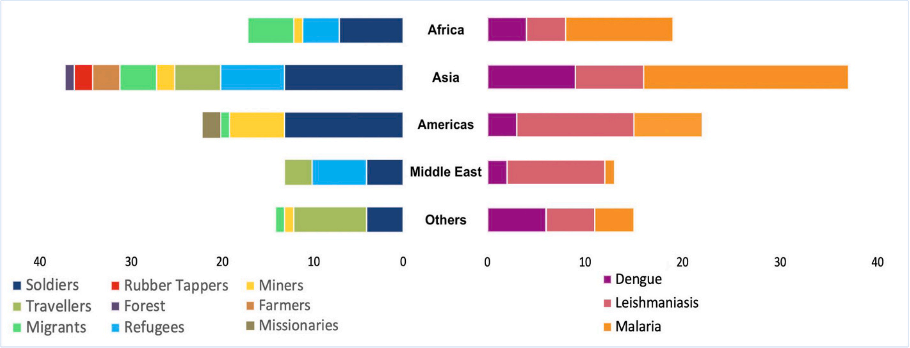

Fig. 3. Distribution of articles by continent of endemicity, representing the proportion of studies by population (*left*) and condition (*right*).

operations in Central and South America (Takafuji et al., 1980; Berger et al., 2006).

During the post-World War II conflicts in Indochina, Malaysia and Korea, malaria impact on deployed forces was strongly reduced by the introduction of improved prophylactic drugs and improved vector control and personal protection measures (Pages et al., 2010). Resistance to chloroquine began to emerge during the Vietnam War, endangering military operations by causing malaria deaths that could not be sustained (Modell, 1968; Beadle and Hoffman, 1993). Malaria is and will continue to be a severe danger to troop health and battle preparedness (Sanders et al., 2005). For this reason, vector control and personal protection strategies are crucial to ensuring the operational readiness of armed forces, which are active in the area of outdoor disease control (Burkett et al., 2013). However, compliance of troops with personal protection or drug prophylaxis is generally low (Frances et al., 2003; Brisson and Brisson, 2012).

Dengue has affected soldiers in most major military conflicts. During World War II, there were high morbidity in areas such as Saipan, where nearly 30% of the troops contracted the disease in a period of three months (Pages et al., 2010). During the Vietnam War, about 15% of field evacuations with fevers of unknown origin were associated with dengue fever (Deller and Russell, 1967; Neel, 1991). Dengue fever has been considered to be a possible cause of febrile illness in troops deployed in tropical areas, including U.S. forces in Somalia (1992–1993) and Australian and Italian forces in East Timor (1999–2000) (Sharp et al., 1995; Kitchener et al., 2002; Pages et al., 2010; Gibbons et al., 2012). Dengue fever can cause a significant number of soldiers to become incapacitated because of its high morbidity rates. Soldiers in training and in combat and other people with a similar occupation have round-the-clock exposure (Fig. 4) to these disease vectors based on the region of endemicity. During night manoeuvres or in combat, soldiers can be infected with leishmaniasis (van Thiel et al., 2011) and malaria (Tuck et al., 2003). During the day, soldiers will be exposed to dengue vector bites if their operation is in a dengue-endemic region (Gibbons et al., 2012), especially in urban settings. Tools for a military setting need to be portable and require minimal compliance.

3.6.3. *Travellers and tourists*

Leisure travel in tropical and subtropical regions often involves a lot of outdoor activity that can lead to exposure to leishmaniasis vectors (Berens-Riha et al., 2009; Perez-Ayala et al., 2009). Cutaneous and mucocutaneous leishmaniasis are becoming more common among travellers involved in outdoor activities in endemic areas, and leishmaniasis is among the top 10 diseases affecting the skin in tourists and soldiers returning from endemic countries (Mansueto et al., 2014). Most travellers are unaware of leishmaniasis and the protective measures needed. A survey in Peru revealed that only 6% of 373 travellers to a rainforest area endemic for *Leishmania braziliensis* had heard of leishmaniasis (Bauer, 2002).

Malaria remains an important health threat to non-immune travellers with the explosive growth of global travel. Populations at high risk of acquiring malaria infections include previously semi-immune travellers who visit friends and relatives, business travellers and international tourists with destinations in sub-Saharan Africa and other malaria-endemic regions. In 2018, sub-Saharan Africa, a region with a high intensity of malaria transmission, received an estimated 56.6 million tourists, a 7% increase from the year before (World Bank, 2023). Travellers are important in malaria transmission, especially in pre-elimination settings, because they can reintroduce malaria (Ahmed et al., 2020). Most travel-related malaria cases are associated with poor compliance with existing bite prevention measures such as topical repellents and bednet use (Croft, 2014) or chemoprophylaxis (Tickell-Painter et al., 2017).

Dengue is endemic in most tropical and subtropical countries, which are popular tourist destinations, and thus is a frequent cause of febrile illness among travellers (Halstead and Wilder-Smith, 2019). It has overtaken malaria as the leading cause of febrile illness for those travelling to Southeast Asia (Wilder-Smith, 2012; Halstead and Wilder-Smith, 2019). Travellers not only are at significant risk of acquiring dengue but also contribute to its spread to non-endemic regions (Wilder-Smith, 2012). Between 2015 and 2019 infection rate (IR)/100,000 per year among travellers was 15.8% from Southeast Asia, 6.1% from Asia as a whole, 4.4% from the Caribbean, 3.9% from Central America, and 3.7% from Africa (Gossner et al., 2022). The proportion of febrile travellers returning from tropical and subtropical countries being diagnosed with dengue has increased from 2% in the early 1990s to 16% in 2005 and will likely continue to rise in line with the global increase in dengue (Messina et al., 2019) and also there have been a few reports of autochthonous outbreaks in this region (Gossner et al., 2022).

Tourists are exposed to dengue and leishmaniasis vectors during the day and malaria vectors at night (Fig. 4), and their risk of exposure is related to their activities, duration of stay and type of accommodation. Compared to other vector-transmitted infections when visiting endemic regions, dengue and malaria are most common among tourists (Wilder-Smith, 2012; Doltario et al., 2016). Malaria is more prevalent among men, indicating a relationship with more frequent night-time activity and higher compliance of women with personal protection (Lalani et al., 2016), whereas dengue was recorded equally for men and women (Schwartz et al., 2008).

3.6.4. *Forest workers*

This group includes those who labour in the forest as researchers, forest product harvesters, rubber tappers, or migratory workers. Their activities collectively display a similar exposure pattern to vectors involved with the transmission of dengue, leishmaniasis, and malaria within forested environments (Fig. 4). Because dengue is primarily an urban disease, it is less common among those in rural areas, whereas infections with arboviruses with a sylvatic cycle, such as yellow fever, are often associated with farming on the forest fringe (Kwagonza et al., 2018). Even so, a few studies have identified farming as a risk factor in

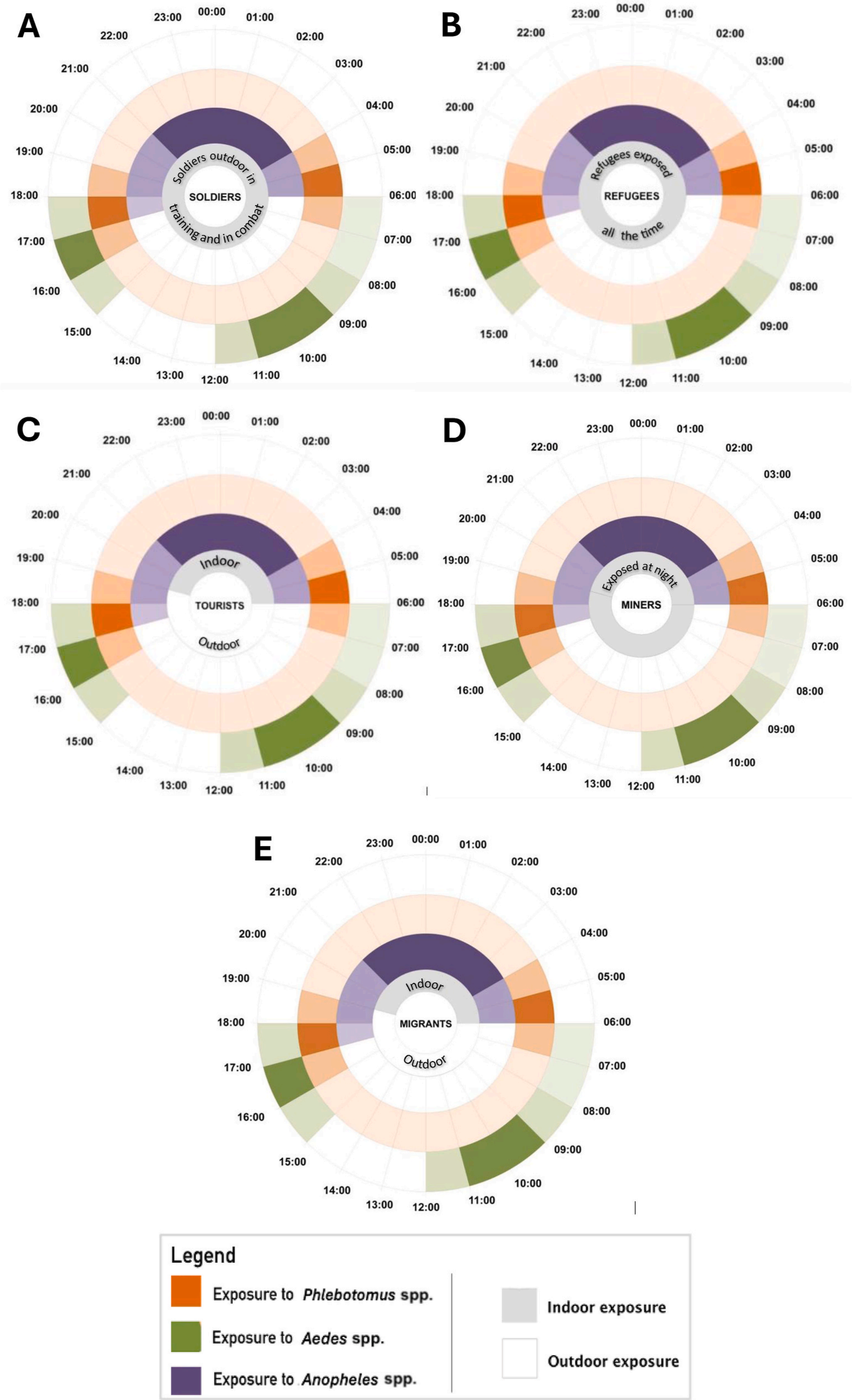

Fig. 4. Occupational exposure to vectors for soldiers (**A**), refugees (**B**), tourists (**C**), miners (**D**) and migrant labourers (**E**).

Vietnam (Phuong et al., 2008), China and Ethiopia because of higher exposure to standing water and exposure to vectors when workers rest in the shade (Ferede et al., 2018; Li et al., 2021). Rubber tappers spend considerable time in rubber plantations, significantly increasing their risk of exposure to arbovirus vectors compared to people who periodically enter forests or remain in the village (Tangena et al., 2017). Among other populations reviewed, dengue was found to be most associated with semi-permanent settlements of poor-quality housing. Dengue outbreaks were observed among migrant workers in camps (Rabaa et al., 2013; Perng et al., 2019) and mine workers where mining created standing water suitable for *Ae. aegypti* breeding (Russell et al., 1996; Eisler, 2003).

In most areas of endemicity, leishmaniasis, specifically cutaneous leishmaniasis, is commonly considered an occupational hazard for forest workers, such as in the Amazon, where there is sylvatic transmission (Lainson and Shaw, 1992). Increased leishmaniasis risk has been recorded in French Guiana when miners go into the forests for work (Mondragon-Shem, 2022). In rural areas in North Africa, farmers are more likely to come into contact with sand flies (*Phlebotomus papatasi*) while conducting irrigation or tending to livestock close to rodent reservoirs of the disease (Bellali et al., 2017; Torres-Guerrero et al., 2017). Economic migrants tend to send money back to relatives in their home country, so it is not unusual for them to sleep in cheap accommodation in temporary houses or near livestock, which increases their probability of infection in Eastern Africa (Argaw et al., 2013).

Increased risk of malaria exposure is seen among rubber tappers (Pattanasin et al., 2012; Jeffree et al., 2018). They commonly work beginning at 22:00 h or midnight and therefore have increased occupational exposure to sand fly vectors (Gradoni, 2018). The most common body part impacted by leishmaniasis in rubber tappers and other forest workers are the ears (Kaya and An, 2024). Among military personnel it is uncovered areas such as the lower arms and head (Lightburn et al., 2002). Rubber tappers work in wet regions in the tropics, which are hot and humid (ILO, 1998); they prefer to dress in clothing that does not totally cover the body, such as shorts and no shirt (Fig. 5). This helps them to cool, allowing evaporation of sweat. At night they sleep in temporary huts, which provide inadequate protection from vector bites (Pattanasin et al., 2012).

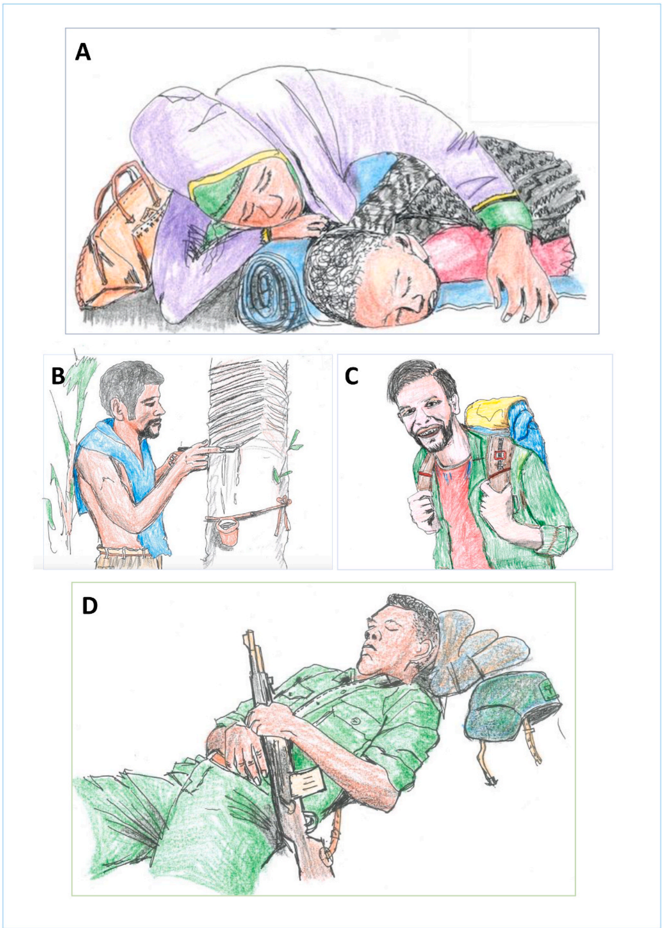

Fig. 5. **A** A refugee woman and her child sleeping outdoors. **B** A rubber tapper wearing limited clothing in a humid climate. **C** A tourist on a trail expedition. **D** A soldier resting after intensive drilling.

One health challenge that forest workers face is the long distance to medical facilities, which can require days of travel time (Ekawati et al., 2020). They must therefore be adequately protected from vector bites before entering forests. Those who stay several days in the forest, such as forest rangers (Rahayu et al., 2020), and those who return daily after work may have different times of exposure to malaria vectors as those who go to the forests and spend more nights there, leading to a higher risk of malaria (Bannister-Tyrrell et al., 2019). Exposure to vector bites increases because of poor sleeping facilities like sleeping outdoors (Fig. 5), in makeshift huts or in improvised ground-level shelters, often in hammocks (von Seidlein et al., 2019). People working in the forests often spend weeks to months at work sites living in poor housing with minimal mosquito prevention tools (Ekawati et al., 2020).

3.6.5. *Mobile populations: miners and migrant workers*

Mobile populations, including migrant workers who move from their permanent residence to malaria-endemic areas for work or other purposes, may be a key cause of spread of malaria infection or even resistance to some antimalarials, as has occurred across the borders of Cambodia, Myanmar and Thailand (Kheang et al., 2018). Miners sleep in huts and makeshift houses and barns that are often not well protected against mosquitoes. Malaria cases represent the largest single portion of the disease burden among Papuan miners in Indonesia (Rodriguez-Fernandez et al., 2016). Frequent cross-border migration in search of employment increases the risk of malaria transmission, as reported among miners (Mondragon-Shem, 2022). It is common for illegal miners to come from non-endemic areas or to not be immune to malaria in the host area (Li et al., 2015). Mining-associated malaria endangers malaria elimination efforts (Hiwat et al., 2012), and miners need to be addressed as a group of particular concern.

Sand flies are usually active at dusk and dawn but can bite even during daytime (Fig. 4) when a host is in proximity (CDC, 2020c). Similarly, migrant workers travel from their home country for temporary, usually seasonal, work (Schicker et al., 2015; Wangroongsar et al., 2016). It has been frequently observed that their accommodation is impermanent or of poor quality and not built to keep away mosquitoes; this is the source of most infection among migrant workers, who at times sleep outside because of heat (Schicker et al., 2015) or stay out late and rise early to start work (Tadesse et al., 2021). Poor housing and early morning or evening outdoor exposure to vectors combine to make their exposure greater at night (Fig. 4).

3.6.6. *Other risk groups*

Men in endemic countries are more susceptible to malaria because of their greater likelihood of working night shifts (Susanna et al., 2012).

Based on time of day, there are four types of exposures: (i) round-the-clock exposure among mobile refugees and soldiers in combat; (ii) night-time occupational exposure among groups that work at night in malaria- or leishmaniasis-endemic areas without dengue transmission, e.g. rubber tappers; (iii) night-time exposure to malaria or leishmaniasis vectors because of poor housing, e.g. refugees in camps, miners and forest workers in temporary shelters; and (iv) daytime exposure among populations active outdoors during the day in urban dengue-endemic areas, e.g. tourists and all urban dwellers.

3.7. *Proposed interventions to combat outdoor exposure*

Of the 99 reviewed articles, 25 suggested means to prevent disease transmission among at-risk populations. Of these, 10 studies (about 10% of the total number of reviewed articles) suggested the use of insecticide-treated clothing (ITC) for prevention of outdoor exposure (Table 5). Prophylaxis was mentioned in 5 articles, vaccination in 4, and topical repellents in 6.

Table 5
Reviewed intervention for outdoors occupation.

Intervention	Advantages	Disadvantages
Chemoprophylaxis (Miller et al., 1999; Behrens et al., 2010; Li et al., 2015)	‣ Available for malaria. ‣ Several types of prophylaxis available to choose from. ‣ Effective when the risk of acquiring infection is high (McBride, 2010). ‣ Cost per person per year for malaria prevention: US $0.53–5.97 (Conteh et al., 2021).	‣ Possible reaction in users (Behrens et al., 2010). ‣ Needs repeated use (Deller and Russell, 1967). ‣ Not for prolonged use (McBride, 2010). ‣ Difficult to adhere (Kitchener et al., 2003). ‣ Intolerance (Kain et al., 2001; Boggild et al., 2007; Gawthrop and Ford, 2009). ‣ Linked to increased parasite resistance (Mika et al., 2008). ‣ Delays disease onset but not infection (Miller et al., 1999).
Insecticide-treated clothing (Soto et al., 1995; Kimani et al., 2006; Kittayapong et al., 2017; Klein et al., 2018; Obwaller et al., 2018)	‣ Prevents bites from all major vectors. ‣ Application lasts for months. ‣ No need for reapplication. ‣ Can also kill vectors, providing possible mass protection if deployed to camps. ‣ Cost per person per year: US$5 (Tozan et al., 2014).	‣ Reaction in some users, but uncommon (Young and Evans, 1998; Sharma et al., 2009). ‣ Efficacy reduced with time and washing (Orsborne et al., 2016; Kittayapong et al., 2017). ‣ There is a limited number of chemicals proved to be safe for treatment while these chemicals are resistant to some vectors. ‣ People may not wear treated clothing for long (Crawshaw et al., 2017). ‣ People may remove clothing when working in hot climates, e.g. tropical forests (Lightburn et al., 2002).
Topical repellents (Klein et al., 2018)	‣ Readily available. ‣ Can be used on exposed skin if long clothing not worn. ‣ Cost per person per year: US$3.80 (Agius et al., 2020).	‣ Needs daily regular reapplication (Gryseels et al., 2015; Crawshaw et al., 2017). ‣ Poor adherence (Gryseels et al., 2015). ‣ Mosquitoes may be diverted to unprotected people (Moore et al., 2007; Maia et al., 2013).
Indoor residual spraying (Jeffree et al., 2018)	‣ Readily available. ‣ Highly effective against malaria (WHO, 2019b), dengue (Vazquez-Prokopec et al., 2017) and visceral leishmaniasis (Rijal et al., 2019); may also be effective against peridomestic cutaneous leishmaniasis (González et al., 2015). ‣ Cost per person per year: US$5.33 in Africa (Yukich et al., 2022).	‣ Must be applied by a trained person (Malaria Consortium, 2021; Sadasivaiah et al., 2007). ‣ Useable only indoors. ‣ Logistically challenging. ‣ Suitable only for semi-permanent settlements (Messenger et al., 2023).
Immunisation/vaccination (Brown et al., 1990)	‣ Prevents disease from developing or reduces severity. ‣ Protects around the clock and long term. ‣ Can be bundled with other vaccination programmes. ‣ Herd immunity: If enough people are immunised against an infection, it is more difficult for it to be spread to those not immunised. ‣ Vaccination helps reduce the social and psychological toll of illness on people and reduce the burden on hospitals and healthcare systems. ‣ Vaccine cost effectiveness similar for leishmaniasis (Bacon et al., 2013), malaria (Galactionova et al., 2017) and dengue in high-burden areas (Perera et al., 2019; Espana et al., 2021; Suwantika et al., 2021).	‣ No available human vaccine for leishmaniasis (Zutshi et al., 2019); leishmaniasis vaccines in development (Claborn, 2010); canine vaccine available (Velez and Gallego, 2020). The first vaccine introduced is only for children and has to be used with other preventive methods (WHO, 2021c). ‣ Malaria has complex stages of the life-cycle but R21, the second malaria vaccine, targets the sporozoite stage only (WHO, 2023b). ‣ Licensed quadrivalent vaccine CYD-TDV available; indicated to people aged 9–45 years and residents of endemic regions with laboratory-confirmed previous dengue infection (Torres et al., 2019); not prequalified by WHO but approved in 19 countries (WHO, 2018; CDC, 2021a). ‣ Vaccine for all four dengue virus strains needed to prevent cross-reaction (CDC, 2022a). ‣ High cost and low uptake.
Spatial repellents (volatile pyrethroids, spatial emanators)	‣ Protect multiple users in a space (Tambwe et al., 2021a). ‣ Multiple modes of action contribute to community and personal protection, i.e. inhibit blood-feeding, incapacitate, kill and reduce mosquito fertility (Bibbs and Kaufman, 2017; Tambwe et al., 2021b). ‣ Reduce malaria in Southeast Asia (Syafruddin et al., 2020) and Africa (WHO, 2023c) and dengue (Morrison et al., 2022). ‣ Cost: US$3 per household per year.	‣ Regular replacement needed (Stevenson et al., 2018; Syafruddin et al., 2020). ‣ Proper disposal needed. ‣ Low temperature and high wind can reduce efficacy (Choi et al., 2016). ‣ Users may not know when the spatial repellent has worn out. ‣ Requires some degree of compliance.
Attractive targeted sugar bait	‣ Attracts and kills mosquitoes and sand flies (Müller and Galili, 2016). ‣ Mortality up to 97% recorded (Fiorenzano et al., 2017). ‣ Can be used both indoors and outdoors against both male and female mosquitoes (Maia et al., 2018b). ‣ Can be used with multiple active ingredients for insecticide resistance management (N'Guessan et al., 2007; Asidi et al., 2012). ‣ Minimal impact on non-target organisms (Müller et al., 2010; Khallaayoune et al., 2013; Müller and Galili, 2016).	‣ Community-based intervention; mosquitoes may be killed in the vicinity away from the user and the user may not perceive the benefits (Maia et al., 2018b). ‣ May affect non-target insects when disposed of, including pollinators. ‣ Difficult to protect the baits for long periods from dust and rain (Müller and Galili, 2016). ‣ Cost has not been calculated. ‣ No evidence of clinical efficacy although trials ongoing.
Wolbachia endosymbionts	‣ Can infect wide range of mosquitoes (Popovici et al., 2010; Vavre and Charlat, 2012). ‣ Drive into the population through cytoplasmic incompatibility, reducing need to reapply (Werren and Bartos, 2001).	‣ Community trust and acceptance of a mosquito-release program takes time (Ong, 2021). ‣ Sometimes *Wolbachia* endosymbionts are lost, and more releases are needed (Ant et al., 2022).

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Table 5 (*continued*)

Intervention	Advantages	Disadvantages
	‣ Have reduced dengue, chikungunya and Zika in multiple settings (Ant et al., 2022). ‣ ‣Cost-effective for endemic urban areas (Brady et al., 2020).	
Gene drive using non-Mendelian inheritance to modify mosquitoes for population suppression or replacement with refractory strains (Alphey et al., 2020; Leung et al., 2022)	‣ Expected to prevent the target infections from spreading, which will lower human morbidity and mortality, provided engineered mosquitos are present at sufficiently high frequencies (James, 2005).	‣ Mosquitoes or parasites may evolve mechanisms to evade to genetic constructs (Wedell et al., 2019). ‣ Possible unknown consequences of incorporation of genetic material into unintended populations or species (Wedell et al., 2019). ‣ Public distrust of genetic modification (Collins, 2018). ‣ Research still in early stages.

Table 6
Interventions against disease vectors of dengue, malaria and leishmaniasis by target vector.

Intervention	*Aedes* spp.	***Anopheles*** spp.	Sand flies
Indoor residual spray	✔ [a]	✔ [a]	✔ [a]
Insecticide-treated clothing	✔ [b]	✔ [a]	✔ [a]
Insecticide-treated bednets	NA	✔ [a]	✔ [a]
Insecticide-treated hammock nets	NA	✔ [a]	?
Spatial repellent	✔ [a]	✔ [a]	?
Topical repellent	✔ [b]	✔ [c]	✔ [b]

Abbreviation: NA, not applicable.

[a] Evidence of clinical efficacy used indoors but bite prevention demonstrated indoors and outdoors.

[b] Bite prevention only.

[c] Evidence of clinical efficacy in areas of forest malaria.

4. Discussion

Malaria has the highest rate of infection in Africa (WHO, 2022b, 2023c) among the three diseases under evaluation, which include dengue and leishmaniasis. The continent was underrepresented in studies that looked at occupational or outdoor exposure to malaria and other vector diseases. Nearly as many studies were conducted in Asia as in Africa and South America combined. Furthermore, leishmaniasis, which is also prevalent in the Horn of Africa, was rarely reported, and the majority of the limited studies that addressed leishmaniasis in Africa were of poor quality and did not meet the risk of bias threshold of 5 points (Supplementary Table S4). There are, therefore, very scarce data for leishmaniasis epidemiology in Africa. Other investigators have identified this gap of knowledge about prevalence and severity of the condition in Africa (Sunyoto et al., 2018) despite the negative consequences for those with untreated disease and the high risk among the large African refugee population (UNHCR, 2022a) from leishmaniasis and malaria (Amodu et al., 2020; Salami et al., 2020), with especially high mortality (18% of refugee deaths) from malaria (UNHCR, 2022b).

The literature search showed groups with the highest frequency of infections to be soldiers, refugees, travellers, migrants, miners, farmers, missionaries and forest workers, in that order. However, this appears to be publication bias. Soldiers make up a fraction of outdoor workers but happen to be the most studied for outdoor transmission of disease vectors. Military care for troops and adequate research funding have resulted in soldiers being relatively well studied in adequately designed studies and in extensive innovation in personal protection (Kitchen et al., 2009). Comparatively little data are available in the peer-reviewed literature on vector-borne disease for refugees despite their large population and relatively high burden of vector-borne disease. Other groups, such as fishers and farmers, are not well covered or clearly assessed and presented by robustly designed studies (Messenger et al., 2023).

Occupational exposure occurs among those practising subsistence agriculture and fishing, working mainly outdoors in fields and sleeping in poor housing (Monroe et al., 2019b; Swai et al., 2019), although this group is relatively poorly studied. Similarly, several articles described infection among travellers and tourists while visiting an endemic area or when they returned to their homes in places mostly non-endemic to these diseases. It may be assumed that this bias is due to the difference in health budgets and the strength of disease-reporting systems between endemic countries and countries from which the tourists originate.

4.1. Infection risk difference across groups

The risks that leishmaniasis, dengue and malaria pose to outdoor workers differ from those they pose to the general population, but outdoor workers remain a small population among the overall global burden of disease. By far the populations with the greatest risk of disease from outdoor exposure or poor housing are refugees and other displaced populations. Their number is climbing because of conflict, with 7 million refugees (UNHCR, 2022c) and 14 million displaced people (IDMC, 2022) in sub-Saharan Africa and 2.4 million refugees (UNHCR, 2022c) and 1.2 million displaced people (IDMC, 2022) in the Middle East in 2021.

In regions where forest malaria is common, the prevalence of malaria is often higher compared to the general population (MacDonald and Mordecai, 2019; Sandfort et al., 2020). Outdoor workers are exposed both while working outdoors and when they return home. However, the groups which bear the heaviest malaria burden are pregnant women (Pavli and Maltezou, 2010; Pell et al., 2011; Quaresima et al., 2021) and children under the age of five years accounted for around 80% of all malaria deaths worldwide in 2021 (WHO, 2023a); global estimates of other years show this age group accounts for about 90% of all malaria-related deaths (CDC, 2022b). A modelling study has estimated that 10% of malaria cases in Africa (10.6 million cases) are from outdoor transmission (Sherrard-Smith et al., 2019).

Very limited information is available for leishmaniasis because of the type of population it affects, usually, the very poor and marginalised; what information has been collected is inadequate and incomplete even for countries where the disease is prevalent (Alvar et al., 2012). The Global Burden of Disease study has shown that this disease prevalence has doubled in the last 30 years, and this growth is highly related to displaced populations.

Groups at risk of dengue and a high disease burden are still seen in tropical regions of Africa. Africa now has 16% of the world's dengue cases, higher than previously thought because of underreporting and varied treatment-seeking behaviour. It is a major hidden burden (Endy et al., 2011; Kakkar, 2012). Dengue fever and dengue haemorrhagic fever are a concern globally, with the highest incidence among children aged 5–14 years in the Americas. Most (75%) of the population exposed to dengue lives in Asia-Pacific, with 1.3 billion at-risk individuals in 10 Southeast Asian countries. Dengue is a leading cause of hospitalisation and death in children in the region (Gubler, 2002; WHO, 2011). It is predominantly acquired outdoors, especially during the day, when the mosquitoes that transmit the virus are most active.

4.2. Control of outdoor transmission: vaccines and drugs

A large number of interventions are available for preventing vector-borne diseases transmitted outdoors (Williams et al., 2018). These may act on the individuals, who are mobile or be applied at a community level in temporary settlements such as mining camps or more permanent settlements such as refugee camps. Relatively inexpensive chemoprophylaxis (Tickell-Painter et al., 2017) and treatment (WHO, 2021b) are available for malaria, and a vaccine is available but not scalable for mobile populations (Alonso, 2021). Although a quadrivalent dengue vaccine has been developed, it is still not widely used and is not suitable for dengue-naïve individuals (Godói et al., 2017). Because of the geographical spread of dengue and dengue haemorrhagic fever and increased incidence in the last 20 years, management of the infection has become essential (Gubler, 1998b; Msellemu et al., 2020). Vector control is the primary means of dengue control, but even in countries with well-organised vector control, it is at best partially effective (Achee et al., 2015). There are no vaccines or drugs to prevent leishmaniasis (CDC, 2020a), and control depends on the setting, i.e. where the vector can be reliably located.

4.3. Transformative technologies: Modern interventions to control disease vectors

Wolbachia-based interventions and gene drive are recent advanced transformative technologies with the potential to revolutionise the control of arboviruses and malaria. *Wolbachia* spp. are naturally occurring bacteria that spread through a population through cytoplasmic incompatibility whereby the *Wolbachia* symbiont-carrying mosquito favours the spread of maternally transmitted *Wolbachia* spp. within the population (Shropshire et al., 2020). *Wolbachia* endosymbionts affect sperm, causing catastrophic effects on the fertilised embryo and ensuing lethality in crosses between symbiotic males and wild-type females, although the embryo will develop in the offspring of *Wolbachia*-carrying males and *Wolbachia*-carrying females. An additional benefit is that harbouring *Wolbachia* can prevent mosquitoes from transmitting diseases such as dengue, chikungunya and Zika (Ant et al., 2022). *Wolbachia*-based interventions, which are considered cost-effective for high-density urban populations, have been able to control arbovirus disease, as demonstrated by multiple trials in tropical cities (Ng, 2021; Ant et al., 2022; Velez et al., 2023).

Gene drive is a technology that allows researchers to rapidly spread a beneficial genetic trait through a population of insects. Engineered snippets of DNA are introduced into an organism's genome to significantly increase the chance that a desired genetic trait will spread through a population faster than would normally happen through sexual reproduction through non-mendelian inheritance (Marshall et al., 2020). Gene-drive organisms are intended to spread a desired trait into a population containing two introduced linked sets of genetic modifications. The first set includes the genetic modifications that encode the new trait. The second set imparts the ability to "drive" the trait into a wild population with a far higher probability than would normally occur (Marshall et al., 2020). For malaria control, population suppression trains are being explored by manipulating sex ratios (Kyrou et al., 2018) and refractoriness to malaria by including antimicrobial peptides that kill *Plasmodium* spp. (Hoermann et al., 2021) so the mosquitoes cannot transmit malaria.

The advent of these technologies coincides with a decline in the efficacy of traditional vector-control methods, such as IRS, due to the emergence of insecticide resistance in mosquitoes (Tungu et al., 2023) and more difficult to implement because of population growth in malaria-endemic areas and tropical cities. As a result, there is a growing need for new tools to complement existing control measures and help reduce the spread of disease. Both gene drive and *Wolbachia*-based interventions are self-sustaining because they spread through a mosquito population; researchers can thus effectively reduce the transmission of disease without the repeated use of control measures and have the potential to be more sustainable in the long term. Both technologies will need to be integrated with other control measures, including community education, surveillance, standing water removal, and larvicide/insecticide use, and both require oversight to monitor programme effectiveness. Finally, it is important to carefully consider the potential risks and benefits of these technologies before deploying them on a large scale. Further research and development are needed to ensure that they are safe and effective and that their deployment does not have unintended consequences for the environment or human health. However, because of the nature of these technologies, they are more suitable for permanent settlement areas than for protecting those who work outdoors in rural or remote settings.

4.4. Control measures for people living in permanent settlements

Dengue epidemics among refugee populations are best tackled in the same way as in urban settlements because most refugees spend a period of several years in camps (Devictor and Do, 2016). For this reason, cost-effective source reduction, i.e. targeted prevention of breeding in highly productive mosquito breeding sites such as water storage containers (Andersson et al., 2015), is essential, and IRS could also be protective (Samuel et al., 2017), especially in outbreaks (Vazquez-Prokopec et al., 2010). Removal trapping may be useful because it is portable and relatively cheap, but evidence of impact on disease is currently limited (Oliver et al., 2021). There is also evidence of the efficacy of spatial repellents (SR) against dengue (Morrison et al., 2022).

Where peridomestic leishmaniasis transmission occurs, vectors are often found in and around houses. Currently, control ranges from none in Syria, where cases are escalating (Rehman et al., 2018), to highly organised and efficient control in some areas of India, resulting in a strong downward trend in cases (Kumar et al., 2020). Where peridomestic leishmaniasis transmission occurs, IRS is efficacious (Joshi et al., 2009), and ITNs with a small mesh size have been shown to reduce the disease incidence (Chowdhury et al., 2019).

Similarly, for malaria in Africa, where transmission is primarily indoors (Pluess et al., 2010) and ITNs have been shown to significantly reduce malaria incidence (Pryce et al., 2018), ITNs and IRS are the most effective tools against malaria (WHO, 2021b) and have been applied at scale with excellent results (Bhatt et al., 2015). Source reduction is often effective in water-limited areas (Bayoh et al., 2011) and may become more important now that *An. stephensi*, an invasive vector species that bites and rests outdoors has been observed in areas hosting internally displaced people (Allan et al., 2023). Where malaria vectors bite and rest outdoors, ITNs and IRS are still used although their efficacy may be compromised (Table 6), Additional control needs to be situation-specific, such as mass drug administration in areas of low and/or seasonal transmission (UNHCR, 2022b). Evidence is being collected for the public health benefit of ATSB although entomological trials are promising and additional tools are required to address mobile populations (Sandfort et al., 2020; Attractive Targeted Sugar Bait Phase III Trial Group, 2022; Ferreira et al., 2022).

4.5. Personal protection methods for mobile populations

Individuals should always take steps to reduce contact with the vectors of dengue because they bite throughout the day; with leishmaniasis vectors, especially in poor housing; and in areas with sylvatic transmission and malaria vectors if outdoors at night.

Protection from sand fly- and *Anopheles* vectors requires similar measures. It is recommended to avoid contact with vectors by minimising nocturnal outdoor activities, especially from dusk to dawn, when sand flies and mosquitoes generally are the most active; to wear clothes that cover most of the body (Kiviat, 1993; Moore et al., 2012; CDC, 2020a); and to use an ITN while sleeping (WHO, 2021b). Where culturally appropriate, mobile outdoor populations may use hammock nets (Table 6) that reduce bites (Sochantha et al., 2010) and reduce malaria (Magris et al., 2007; Thang et al., 2009). If vectors are active during sleeping hours, people must rely on bite prevention by using topical mosquito repellents (Lupi et al., 2013), ITC (Banks et al., 2014), and volatile pyrethroid spatial repellents (Maia et al., 2018a). Insect repellents containing a minimum of 20% N, N-diethyl-3-methylbenzamide (DEET), 20% picaridin or 20% p-menthane-3, 8-diol (PMD, 65% citriodiol) have been effective in preventing *Anopheles* and *Aedes* mosquito (Lupi et al., 2013) and sand-fly bites (Diaz, 2016), and there is some evidence of protection against forest malaria (Hill et al., 2007; Agius et al., 2020).

Similarly, protective clothing impregnated with permethrin is efficacious against all mosquito- and sand-fly bites (Jelinek, 2000; Wilder-Smith and Schwartz, 2005) and has good evidence of bite prevention (Banks et al., 2014) but not of disease protection against dengue (Kittayapong et al., 2017), with some evidence of prevention of malaria (Maia et al., 2018a) and leishmaniasis (Reyburn et al., 2000). For mobile populations that wear long clothing, the use of ITC is more sustainable and requires lower individual compliance with the intervention.

Spatial repellents (SR) function by evaporating into the air, establishing a protective zone to repel or eliminate insects (Ogoma et al., 2012). They can protect multiple people within the treated space (Tambwe et al., 2021a). The active ingredients, often volatile pyrethroids, impact the nervous system of insects, disrupting their normal functions and deterring them from landing or biting (Valbon et al., 2022). Activation of SR by an external energy source for dispersal characterizes it as an active emanator. Conversely, a passive emanator is an SR that gradually releases insecticides into the environment over time, operating independently without the requirement of external energy. Passive emanator spatial repellents are advantageous because they rely solely on natural air movement to emanate active ingredients from a dosed surface into a space so can be used in rural areas without electricity (Darbro et al., 2017).

Spatial repellents using a light, portable passive plastic emanator have been shown to protect against dengue (Morrison et al., 2022) and malaria (Maia et al., 2018a; Syafruddin et al., 2020; WHO, 2023d) in randomised control trials. A third trial showed a reduction in malaria although it was flawed due to no malaria transmission occurring in several clusters (Maia et al., 2018a; Syafruddin et al., 2020; WHO, 2023d). Evidence for bite prevention both indoors and outdoors for this intervention is extensive (IVCC, 2020). SR using passive emanators have also provided effective personal protection against vector-borne disease exposures of malaria in the forests (Charlwood et al., 2016; Tangena et al., 2018; Chen et al., 2023). However, evidence is limited for leishmaniasis since very little research has been done on this neglected disease, although operational trials are underway for leishmaniasis (The MENTOR Initiative, 2020) as well as malaria in displaced populations in Nigeria and Yemen and Uganda (Achee et al., 2023). SR may be used in addition to other interventions such as ITNs to provide additional layers of defence against mosquito bites (Dev, 2021) that in some instances can last for up to a year without the need for compliance (Swai et al., 2023a). This is an important feature, since topical repellents are generally not used frequently (Gryseels et al., 2015). Importantly, SR also cause mosquito mortality (Swai et al., 2023b) that contributes to community protection (Denz et al., 2021; Fairbanks et al., 2023).

4.6. *Personal protection interventions versus community control*

Research efforts should be directed towards devising novel interventions, including vaccines, with the potential to benefit a wider range of people. The focus of research on vector-borne diseases should also aim at scaling up innovations and interventions that will benefit the most vulnerable groups, including children and displaced populations.

Personal protection is essential for those who work outdoors in vector-prevalent regions because it provides a more effective way of controlling occupational exposure than community control interventions. Community interventions may provide good protection in areas of permanent or semi-permanent settlements but are ineffective when the population is mobile. Tailoring the intervention to fit the specific needs of individuals (Bancroft et al., 2022) and their duties may improve adherence and therefore provide more efficient protection. For those sleeping in unimproved housing, the addition of volatile pyrethroids may provide additional protection against mosquito bites (Fairbanks et al., 2023).

4.7. *Insecticide-treated clothing (ITC)*

It is a suitable intervention for mobile populations needing round-the-clock protection or outdoor protection during the day in dengue-endemic areas or at night in malaria- or leishmaniasis-endemic areas. ITC was the most frequently mentioned intervention and has evidence of protection for outdoor workers against mosquito and sand-fly bites (DeRaedt Banks et al., 2015; Londono-Renteria et al., 2015; Ghamari and Khoobdel, 2019) but also against malaria (Soto et al., 1995; Maia et al., 2018a) and leishmaniasis (Reyburn et al., 2000). This intervention may be effective for long-term users, such as refugees, soldiers in combat and forest rangers ranging from a month to a year or more because treated clothing has an excellent toxicity and safety profile for long-term use (Rossbach et al., 2010; EPA, 2023). Short-term users are those who will need the intervention for a few weeks or months; these include tourists, miners and migrant workers. For those sleeping at night in malaria- or leishmaniasis-endemic areas, the use of an ITN is also recommended (Chowdhury et al., 2019; WHO, 2021b).

Not all occupations will benefit equally from ITC. Acceptance of and adherence to ITC may depend upon occupation and cultural norms for body covering (Table 7). Occupations that require a uniform, such as military personnel and forest rangers, will benefit from ITC more than those not required to wear a uniform and who may prefer short clothing with less coverage, including miners, rubber tappers, migrant workers and loggers. Combining ITC with additional interventions such as topical or spatial repellents may be optimal for round-the-clock protection.

ITC is not always optimally effective. Incorrect use, such as rolling up sleeves (Wallace et al., 1996), can undermine efficacy (Fig. 5). Some studies have suggested that improved wash resistance is needed (DeRaedt Banks et al., 2015; Kittayapong et al., 2017). When treated clothes are industrially impregnated, their efficacy lasts longer (DeRaedt Banks et al., 2015). The need for additional topical repellents for personal protection on soldiers in endemic regions during recreation, when uniforms are not used, has also been emphasised (Obwaller et al., 2018). Even so, ITC using pyrethroids is safe (National Research Council, 1994; Young and Evans, 1998), requires lower compliance than topical repellents and is relatively inexpensive, giving excellent cost benefits, especially to non-immune individuals (Soto et al., 1995). A useful feature of ITC is that it generally exerts some knockdown and kill of vectors (National Research Council, 1994) that will prevent vectors from moving from a protected to an unprotected individual (Moore et al., 2007). Killing, knockdown and feeding inhibition reduce vectorial capacity if applied at scale (Denz et al., 2021). This, combined with excellent bite prevention (Banks et al., 2014), user acceptance (Forgearini et al., 2016; Crawshaw et al., 2017) and some evidence of efficacy against malaria (Maia et al., 2018a) and leishmaniasis (Soto et al., 1995; Reyburn et al., 2000), makes self-treated clothing (Forgearini et al., 2016) optimal for those exposed to vectors round the clock, during the day in dengue transmission areas or while working at night (Li et al., 2015).

While ITC offer promise in shielding individuals outdoors, distinct from other vector control measures, they rely on insecticides akin to those utilized in interventions like IRS and ITNs. With vector resistance emerging against these insecticides, the efficacy of ITC is challenged. Therefore, it is imperative to explore the utilization of alternative insecticides that have not yet encountered vector resistance. By adopting

Table 7
Suitable interventions for various occupations in varying situations.

Occupation	Duration of exposure	Context	Proposed intervention	Local customs
Soldiers	Short	Training	ITC; Topical repellents	Follow orders
	Long	Active combat	ITC; Topical repellents	
Refugees	Short	War and natural calamities	ITC; Spatial repellents;	Clothes cover the whole body
	Long	Host country	IRS; ITN; Improved housing; Spatial repellents	
Tourists	Short	Tour	ITC	Customs and health-seeking behaviour
	Long	Expatriate/Vacationing	ITC; IRS; ITN; Spatial repellents	
Miners	–	Legal, formal	ITC; Topical repellents; Spatial repellents	Follow orders
	–	Illegal, informal	ITC; ITN; Topical repellents; Spatial repellents	Anarchic
Migrant workers	Short	Seasonal	Prophylaxis	Follow orders
	Long	Permanent	IRS; ITN; Spatial repellents	Anarchic
Farmers	Short	Seasonal	ITN; Spatial repellents	Anarchic
	Long	Permanent	ITC	
Forest workers	Short	Temporary	ITC; Topical repellents; Spatial repellents	Follow orders
	Long	Permanent	ITC; Spatial repellents	Anarchic
Rubber tappers	Short	Temporary	Spatial repellents; ITC	Follow orders
	Long	Permanent	Spatial repellents; ITC	Anarchic
Missionaries	Short	Sabbatical	Topical repellents; Spatial repellents; ITC	Health-seeking behaviour
	Long	Mission	Improved housing; ITC; ITN; Spatial repellents	

Abbreviations: IRS, indoor residual spraying; ITC, insecticide-treated clothes; ITN, insecticide-treated nets.

such innovative strategies, the efficacy of ITC can be enhanced and ensure robust protection against the threat of vector-borne illnesses in outdoor environments. That is, continual efforts to improve and use utilize innovative personal protective tools remain imperative (Sharp et al., 1995; Wallace et al., 1996) until vaccines for malaria, dengue and leishmaniasis become available.

4.8. Study limitations

The review relied upon observational studies, which lack the experimental element of a random allocation of exposure or intervention, so the evidence presented depended on associations shown by the studies. Studies of risk factors typically cannot be randomised because they relate to innate human characteristics or habits and because randomisation exposes individuals to dangerous risks (Stroup et al., 2000). Because it is thus not possible to measure rates and patterns of disease using prospective designs (Ioannidis and Lau, 1999; Munn et al., 2020), retrospective non-randomised studies study designs are best used to assess relationships between possible exposure and disease outcomes to form hypotheses regarding risk or prevention (Munn et al., 2020). This is a challenge when conducting a systematic review of non-randomised studies because most reporting guidelines are designed for prospective randomised study designs (Shea et al., 2017; Oxman, 2018). Although meta-analytic techniques are routine in the synthesis of data from randomised controlled trials, there are no clear guidelines on how to best summarise frequency data such as incidence and prevalence estimates (Saha et al., 2008). Therefore, this systematic review of observational articles providing data on the incidence and prevalence of infections of dengue, leishmaniasis and malaria used a framework comparator CoCoPop mnemonic developed by Munn et al. (2015) specifically for prevalence and incidence reviews with additional criteria for study design, as per the PRISMA statement (Moher et al., 2009). The review synthesised the incidence and prevalence of studies that report infections and diseases resulting from occupational exposure to malaria, arbovirus and leishmaniasis vectors whilst adhering to the same basic principles of systematic review of other types of data (Moher et al., 2009). However, meta-analysis was not possible. By nature, observational studies are more at risk of confounding factors and various unavoidable sources of bias (Munn et al., 2020). Because of the weakness of non-randomised studies, this review provides weaker evidence than a review of prospective randomised trials.

5. Conclusion and recommendations

The review indicates that the timing and location of vector exposure are critical factors to consider for the control of vector-borne disease. These factors can be grouped as (i) round-the-clock outdoor exposure, (ii) daytime outdoor exposure, (iii) indoor night-time exposure or (iv) outdoor night-time exposure, and subdivided into the population categories: mobile and living in semi-permanent settlements of poor housing.

ITC is a favourable intervention for outdoor use, especially among mobile populations, and has the potential to protect soldiers, refugees without shelter and tourists, although its use can be impaired by partial adherence, particularly when short clothing is more commonly worn or where environmental conditions make the wearing of long clothing uncomfortable.

Those living in semi-permanent settlements, such as migrant workers (e.g. rubber tappers, gold miners) and refugees, will need multiple interventions tailored to their ecological setting to protect them from peridomestic transmission. IRS and ITNs or insecticide-treated hammock nets have the greatest weight of evidence for control of malaria, leishmaniasis and dengue in the peridomestic setting. For unimproved housing and possibly forest shelters SR holds excellent promise to provide protection against indoor biting disease vectors (Fairbanks et al., 2023). ITC and repellent may be needed for those with day- or night-time occupational exposure away from their living quarters. However, the evidence for ITC as a public health intervention is currently restricted to a handful of small studies, with most research conducted among military populations even though refugees are the population most at risk of severe morbidity or mortality from vector-borne disease. However, a number of operational trials are ongoing to evaluate the impact of SR for disease prevention among these vulnerable groups (Achee et al., 2023). Self-treatment of clothes should be encouraged as a disease vector intervention in dengue-, leishmaniasis- and malaria-endemic areas, particularly for individuals who cannot afford multiple outfits that need to be changed regularly. While the evidence for disease prevention is limited, it is known that insecticide-treated clothing and SR effectively prevent bites as well as contributing to mosquito mortality which will protect both users and non-users of these interventions (Fairbanks et al., 2023).

Although people occupationally exposed to vector-borne diseases, such as soldiers and travellers to endemic areas, may have a higher disease prevalence (Antinori et al., 2012; Wilder-Smith, 2012; Marasinghe et al., 2020), the local population in the endemic area still experiences the largest absolute number of infections (CDC, 2021b; WHO, 2022b). This highlights the need to address the issue of sustained control of vector-borne diseases in the local population in addition to supplemental control for occupationally exposed groups to control the spread of these diseases.

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CRediT authorship contribution statement

Daniel Msellemu: Conceptualization, Methodology, Writing – original draft, Formal analysis, Visualization, Writing – review & editing. **Marcel Tanner:** Writing – review & editing, Supervision. **Rajpal Yadav:** Methodology, Writing – review & editing. **Sarah J. Moore:** Conceptualization, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The views expressed in this article are solely the responsibility of the authors and do not necessarily reflect the perspectives, choices, or policies of the institutions to which they are affiliated.

Data availability

The data supporting the conclusions of this article are included within the article and its supplementary files.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crpvbd.2024.100185.

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