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Literature Review on Malaria in Saudi Arabia

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Abstract

Significant progress has been made in malaria control worldwide over the past decade, and as more countries enter the malaria elimination phase, attention is now focused on identifying effective strategies to reduce the incidence of malaria. Saudi Arabia experienced a malaria outbreak in 1998. In Saudi Arabia, malaria control is a major challenge, with many cases attributed to imported cases in the regions and cities of Jazan, Makkah, Madinah, Jeddah, and Asir. Jazan has the highest number of malaria cases in the Kingdom.

Keywords

Malaria, Saudi Arabia, Malaria Systematic Data

1. Introduction

Malaria disease has caused significant global havoc over the last few centuries. The infection of malaria is caused mainly by the biting of infected mosquitoes, which may lead to life-threatening complications for humans. Thus, this disease creates a significant global public concern, especially in the subtropical and tropical regions of the world [1]-[3]. In this case, malaria is endemic since it affects over 90 countries and over 40% of the world's population [4]. In the Kingdom of Saudi Arabia (KSA), the measures to prevent the spread of malaria were enforced in 1948 to reduce widespread severe infections among workers in the Eastern region [4]. However, the prevention program extended countrywide in 1952 to target the most malaria-prone areas in the Eastern, Northern, and Western regions of the KSA. However, the current prevalence rate of the disease in Saudi Arabia is that over 1000 cases have been reported annually since 2000, with the highest numbers found in Jazan and the lowest cases identified in the Qurrayaat area [5]. The above statistics make the topic of malaria disease in KSA significant since it reveals that the interventions enforced by the government of Saudi Arabia are not effective in eliminating this problem from the country. Therefore, this literature review aims to provide a systematic study of the prevalence of malaria in Saudi Arabia by focusing on the analysis of the existing literature on five critical subtopics about the disease, including the history of malaria in Saudi Arabia, epidemiology of the disease in the country, high-risk populations and hard-to-reach areas, last indigenous malaria cases and foci in the country, and entomological aspects of malaria transmission.

2. Methods

A literature review and analysis were conducted through an extensive search of PubMed and Google Scholar using the terms (malaria - Malaria systematic data and Saudi Arabia). Focusing on five important subtopics of the disease, including the history of malaria in Saudi Arabia, the epidemiology of the disease in the country, populations at risk and hard-to-reach areas, recent indigenous malaria cases and foci in the country, and entomological aspects of malaria transmission. This search yielded over 2800 articles, and duplicate studies and irrelevant papers were excluded. This literature review covered the initial task determined by WHO to be culminated in to reach elimination stage.

3. Task 1: History of Malaria in Saudi Arabia

3.1. Characteristics and Changes in the Epidemiology of Malaria over Time

Elagali *et al.* [4], Al-Mekhlafi *et al.* [5], and Hassanein *et al.* [6] agree that malaria's epidemiology in Saudi Arabia is variable since the trends depict variation from one region to another and location to location within the same region. Thus, Elagali *et al.* [4] note that malaria epidemiology in Saudi Arabia varies depending on the areas and locations within one region because of the vast geographical space in the country and dynamic weather in diverse areas. Thus, they note that these changing conditions are vital in influencing malaria distribution by affecting the existence of particular species, their life cycles, and the overall mosquito distribution in the country. Al-Mekhlafi *et al.* [5] agree with the findings of Elagali *et al.* [4] by indicating that malaria's epidemiology in KSA depicts variability since the prevalence is different from location to location since the country is largely a desert with differing climatic conditions in various regions based on the different topographies of the country. Similarly, the findings of Hassanein *et al.* [6] prove the variability in the epidemiology of malaria in KSA. In this case, Hassanein *et al.* [6] concluded that malaria's epidemiology in the country varies from one year to another and one region to another, including locations within the same region. Therefore, Elagali *et al.* [4], Al-Mekhlafi *et al.* [5], and Hassanein *et al.* [6] demonstrate that malaria epidemiology in the Kingdom of Saudi Arabia varies based on the regions, timeframes, climatic conditions, and topographical differences in several parts of Saudi Arabia.

3.2. Historical Epidemics or Outbreaks

According to a study by Elagali *et al.* [4], early malaria cases were discovered in 1948 when the Arabian American Oil Corporation engaged in prevention programs to control the disease across Saudi Arabia's Eastern region to reduce infections among their workers. The next epidemic was detected in 1952 when the prevention program extended countrywide, targeting the most malaria-prone areas in the Eastern, Northern, and Western regions of the KSA [4]. However, Elagali *et al.* [4], Al-Mekhlafi *et al.* [5], Abdalal *et al.* [7], and Alhaddad *et al.* [8] provide information about recent outbreaks of malaria in KSA despite the variance in periods of the epidemics. For instance, Al-Mekhlafi *et al.* [5] investigated a malaria outbreak between 2010 and 2017 in the Jazan region of Saudi Arabia. They discovered 407 cases out of the population sample 1124 were malaria cases. Despite these findings revealing a significant malaria outbreak in this period, Al-Mekhlafi *et al.* [5] noted that relative humidity and average temperature were the significant determinants of this epidemic. In another study, Abdalal *et al.* [7] examined a malaria outbreak along the Saudi Arabian border between 2015 and 2018 and discovered several disease cases in the area. Thus, Abdalal *et al.* [7] confirm an outbreak of malaria in Saudi Arabia between 2010 and 2018, as indicated in Al-Mecklafi *et al.*'s [4] research. Alhaddad *et al.*'s [8] research also reveals a malaria outbreak in Saudi Arabia that occurred between 2018 and 2022. Alhaddad *et al.* [8] examined malaria cases recorded during the COVID-19 period by focusing their study on the Eastern Saudi Arabian area of Dammam. Alhaddad *et al.* [8] discovered that malaria cases doubled in this region during COVID-19 and concluded that the COVID-19 pandemic significantly negatively affected malaria epidemiology in KSA. Moreover, Alfaleh *et al.* [9] examined the malaria outbreak in KSA between 2017 and 2021 and discovered that several malaria cases were reported in different parts of Saudi Arabia in this period. Therefore, Elagali *et al.* [4], Al-Mekhlafi *et al.* [5], Abdalal *et al.* [7], and Alhaddad *et al.* [8] confirm that malaria epidemics in KSA occurred in different periods.

3.3. Causes of the Epidemics

According to studies conducted by Al-Mekhlafi *et al.* [4], Abdalal *et al.* [7], Monroe *et al.* [10], and Al-Awadhi *et al.* [11], the primary cause of the malaria epidemics in KSA is human factors related to border movements or migration into the country. Monroe *et al.* [10] posit that malaria epidemics in Saudi Arabia are disproportionately distributed in different subpopulations living near border areas. Monroe *et al.* [10] note that individuals living near border regions in KSA interact with malaria-infected individuals from neighbouring countries due to shared behavioural, occupational, and social features, leading to significant malaria outbreaks in Saudi Arabia. These findings are proven by Al-Awadhi *et al.* [11] and Al-Mekhlafi *et al.* [4], who indicate that the 2018 epidemic that led to 2700 confirmed malaria cases in KSA resulted from infection imports from Yemen, Ethiopia, and India. Abdalal *et al.* [7] also present similar findings by noting that border malaria in KSA is a significant threat to the effects of eliminating malaria in the region since nearly one-third of different imported malaria cases are from Yemen. Thus, despite indicating that border movements contribute to the malaria epidemics in KSA, political instability in bordering countries plays a significant role in promoting human movements in the country, which increases the chances for the development of epidemics in Saudi Arabia [7]. Spiritual factors such as annual Islamic worship also contribute to the malaria epidemics in Saudi Arabia due to the pilgrim movements to the country during Hajj, which promotes malaria transmission in such instances [7]. For this reason, Al-Mekhlafi *et al.* [4], Abdalal *et al.* [7], Monroe *et al.* [10], and Al-Awadhi *et al.* [11] prove that the primary cause of the malaria epidemic in Saudi Arabia is human transfers through the country's borders.

3.4. Measures to Contain the Epidemics

Abdalal *et al.* [7], Abdelwahab *et al.* [12], Tripathi *et al.* [13], and Gosadi [14] agree that the Saudi Arabian government intervened to contain the epidemics. According to Abdalal *et al.* [7], the control measures for the epidemics included establishing sustained preventive measures, including the distribution of durable insecticidal nets, indoor spraying, prompt diagnosis, and provision of effective treatment measures in reported cases. Moreover, the KSA government employed high-level surveillance comprising integrated vector control, treatment options, and provision of border control measures through case detection efforts that included screening migrants and offering curative and preventive options for malaria treatment [7]. Abdelwahab *et al.* [12] also indicated the KSA government's efforts to control the malaria epidemic through collaboration with the World Health Organization by engaging in biannual meetings and using mobile units to help immigrants at the border areas. In another study, Tripathi *et al.* [13] confirmed that the KSA took measures to contain the malaria epidemics in the last five decades through insecticide spraying in affected areas, offering effective treatment to victims, and enforcing prevention and protection mechanisms for the citizens. On this note, Tripathi *et al.* [13] and Abdalal *et al.* [7] agree that the Saudi Arabian government used chemical methods, protection and prevention measures, and proper treatment methods to contain the malaria epidemics in Saudi Arabia.

On the other hand, Gosadi [14] notes that the Saudi Arabian government participated in several programs to contain emerging epidemics, such as creating disease notification systems, establishing surveillance systems in the health sector, and assessing community risk levels. In addition, the KSA government implemented interventions, such as immunisation against communicable diseases, screening through healthy marriage programs, and developing the national malaria control program [14]. Therefore, the government's involvement in controlling the epidemics helped reduce malaria infection rates in Saudi Arabia.

Figure 1 below shows that the highest number of malaria cases (over 35,000) was recorded in 1998 before the infection rates dropped significantly from 2000 to below 5000 cases annually.

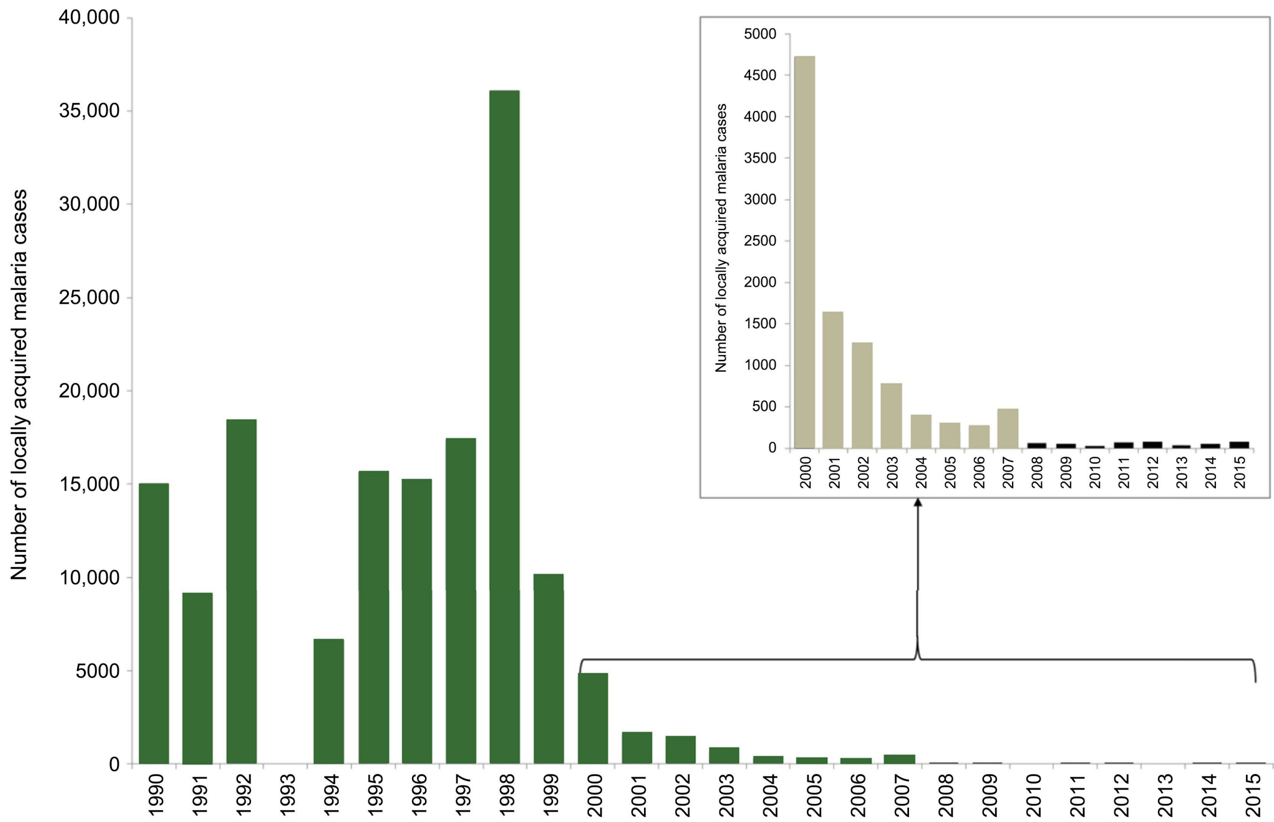

Figure 1. A graph showing the disease trend since the beginning of the malaria program. Source: [35].

3.5. Changes in the Distribution of Vector Species over Time

The history of malaria in Saudi Arabia shows that the vector species distribution in the country is varied depending on topographical, geographical, and socio-economic factors. Madkhali *et al.* [15], the Kingdom of Saudi Arabia Ministry of Health [16], Wilkerson [17], Pecor [18], and El-Eryani [19] focus on vector species analysis within particular regions rather than providing the history of vector species distribution. According to Madkhali *et al.* [15], *Anopheles arabiensis* is the primary vector within Saudi Arabian territory. Moreover, the other existing vector species of Anopheles mosquito in this region include the *Sergentii*, *dthali*, *stephensi*, *culicifacies*, and *fluviatilis* [15]. The data from the Kingdom of Saudi Arabia Ministry of Health [16] also provides similar findings about the Anopheles vector species being the primary vector in the region. On this note, the data reveals that the country has 17 vector species of the Anopheles mosquito from which *Arabiensis*, *Stephansi*, *Superpictus*, and *Sergentii* are malaria vectors [16]. The data also shows that different parts of the country have distinct vectors since the West and Center region experiences the *Sergentii* species, the East region suffers from the *Stephensi* species, the Northern parts face the *Superpictus*, and *Arabiensis* dwells in the South-Western area [16]. However, this data reveals that the most common vector leading to high malaria transmission in Saudi Arabia includes the *An. arabiensis* and *An. sergentii* that lead to infections along the South-West region in the country [16]. Wilkerson [17] and Pecor [18], they note that *An. stephensi* is common in the Middle East region and extends to Saudi Arabia.

Moreover, El-Eryani [19] agrees that *Anopheles arabiensis* is a common vector species in several parts of Africa and extends to Saudi Arabia. However, he predicts that there is a possibility for changes in the Anopheline vector distribution in the near future as the *An. stephensi* might invade Saudi Arabian land to become more predominant [19], as happened in the Eastern Mediterranean Region countries in the Horn of Africa and Yemen. Therefore, Madkhali *et al.* [15], the Kingdom of Saudi Arabia Ministry of Health [16], Wilkerson [17], Pecor [18], and El-Eryani [19] show that the malaria vector distribution in Saudi Arabia depends on regional factors despite the Anopheles vector being a common species in the country despite the differences in their findings.

4. Task 2: Epidemiology of Malaria in the Country

4.1. The Geographic Distribution of Malaria Transmission in Saudi Arabia

Elagali *et al.* [4], the Kingdom of Saudi Arabia Ministry of Health [16], Al Jurebi *et al.* [20], and Dablool and Hamdoon [21] agree that malaria prevalence in different regions of the country has been changing with time due to the interventions enforced by the government to control the disease. **Table 1** shows that P. falciparum has been the dominant malaria species between 2013 and 2022. Moreover, **Table 2** reveals that the population subjected to malaria tests has declined since 2019, with the total number of tests falling below one million. **Table 3** contains data proving that Plasmodium Falciparum is the most common malaria species in Saudi Arabia. On the other hand, **Table 4** shows the need for more data on relapsing and induced malaria cases in Saudi Arabia since 2012.

Table 1. Annual malaria cases by species and malaria deaths over the past 25 years.

Annual Malaria Cases

Year	Confirmed cases							Deaths
	Total cases	*P. falciparum*	*P. vivax*	*P. malariae*	*P. ovale*	Mixed infections	Unknown species	
2013	2513	974	764	6	764	6	0	0
2014	2305	1154	571	7	571	0	0	0
2015	1602	1444	582	10	582	2	0	0
2016	5382	3922	710	40	710	0	0	0
2017	2715	1819	443	10	443	0	0	0
2018	2711	1898	401	1	401	10	0	0
2019	2152	1498	314	10	314	16	0	0
2020	3659	3231	210	0	210	8	0	0
2021	2616	2023	240	9	240	104	0	0
2022	4320	3079	590	22	590	39	0	0
2023	6460	3769	2381	36	2,381	274	0	0

Table 2. Malariometric indices, <country> 1.

Year	Total population of country	Population at risk[b]	Number of people tested for malaria[c]	Number of positive parasitological tests	Annual blood examination rate[d]	Test positive rate	Annual parasite incidence
2013	29,994,272	56,989	1,309,783	2513	4.37%	0.19%	4.41%
2014	30,770,375	55,387	1,249,752	2305	4.06%	0.18%	4.16%
2015	31,521,418	63,043	1,306,700	2620	4.15%	0.20%	4.16%
2016	31,742,308	133,318	1,267,933	5382	3.99%	0.42%	4.04%
2017	32,552,336	100,912	862,718	2715	2.65%	0.31%	2.69%
2018	33,413,660	90,217	1,015,953	2711	3.04%	0.27%	3%
2019	34,218,169	65,015	1,118,706	2152	3.27%	0.19%	3.31%
2020	35,013,414	182,070	703,048	3658	2.01%	0.52%	2.01%
2021	34,110,821	139,854	642,818	2616	1.88%	0.41%	1.87%
2022	32,175,224	180,181	764,822	4319	2.38%	0.56%	2.40%
2023	33,702,731	316,805	688,629	6460	-	0.94%	-

The population at risk was defined and estimated by dividing the test positivity rate by the total population of the country. The notable change in population at risk is that the number of people at risk of malaria in Saudi Arabia from 2019 has changed to over 100,000 people per year.

Table 3. Annual Malaria Cases 1. Number of indigenous cases, introduced cases and imported cases by species <from 5 years before first year of zero indigenous cases to present>.

Number of indigenous cases 1

Case classification	Species	2020	2019	2018	2017	2016	2015	2014	2013	2012	Total
Indigenous cases	*P. falciparum*	83	38	57	172	270	83	30	34	83	850
	P. vivax	0	0	4	5	2	0	0	0	0	11
	P. malariae	0	0	0	0	0	0	0	0	0	0
	P. ovale	0	0	0	0	0	0	0	0	0	0
Introduced cases	*P. falciparum*	123	85	133	164	0	-	21	0	0	526
	P. vivax	-	-	-	-	-	-	-	-	-	-
	P. malariae	-	-	-	-	-	-	-	-	-	-
	P. ovale	-	-	-	-	-	-	-	-	-	-
Imported cases	*P. falciparum*	3453	2029	2517	2374	5110	2537	2254	2479	3324	26,077
	P. vivax	-	-	-	-	-	-	-	-	-	-
	P. malariae	-	-	-	-	-	-	-	-	-	-
	P. ovale	-	-	-	-	-	-	-	-	-	-
Total		3659	2152	2711	2715	5382	2620	2305	2513	3404	27,461

Table 4. Annual Malaria Cases 2. Number of relapsing or recrudescent and induced cases <from 5 years before first year of zero indigenous cases to present>.

Number of relapsing or recrudesce 1

Case classification	2020	2019	2018	2017	2016	2015	2014	2013	2012	Total
Relapsing/recrudescent	0	0	0	0	0	0	0	0	0	0
Induced	0	0	0	0	0	0	0	0	0	0
Total										

The World Health Organization report does not classify malaria cases in Saudi Arabia as relapsed or induced. Thus, there is no data to identify such cases. The Ministry of Health in Saudi Arabia also lacks reports of such malaria classifications.

Moreover, **Table 5** reveals the missing data on the nationalities of the imported malaria cases from Saudi Arabia's Ministry of Health or the World Health Organization. Similarly, the Ministry of Health in Saudi Arabia does not provide accessible data on the countries of origin that are impacted by imported malaria cases. Thus, the historic malaria distribution patterns differ from the current geographic transmission areas. (**Table 5**)

Table 5. Annual Malaria Cases 3. Number of imported cases by nationality <from 5 years before the first year of zero indigenous cases to present>.

	Number of imported cases 1								
Nationality	2020	2019	2018	2017	2016	2015	2014	2013	2012
N/A									
Total									

The data examined revealed that neither the World Health Organization nor Saudi Arabia's Ministry of Health has readily accessible data on the number of imported malaria cases by nationality between 2012 and 2020.

Table 6. Annual Malaria Cases 4. Number of imported cases by country of origin <from 5 years before first year of zero indigenous cases to present>.

	Number of imported cases 1								
Country of origin of infection	**2020**	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**
N/A	N/A		N/A		N/A		N/A		N/A
Total									

The data examined revealed that neither the World Health Organization nor Saudi Arabia's Ministry of Health has readily accessible data on the number of imported malaria cases by country of origin between 2012 and 2020.

According to the Kingdom of Saudi Arabia Ministry of Health [16], the early transmission areas were in the Eastern Province, with malaria transmissions recorded in the Eastern Province and Jeddah between the 1930s and 1940s. However, this distribution significantly changed from the year 2000 when malaria transmission was reported in Jazan and Aseer regions [16]. This change in distribution patterns is supported by Al Jurebi *et al.* [20], who indicate that malaria transmission is currently restricted to the South-Western regions of Saudi Arabia, which comprises Jazan and Aseer areas. Al-Mekhlafi *et al.* [5] also agree that malaria transmission in KSA is confined to the South-Western area of the country, which comprises the Jazan and Aseer areas. On the other hand, Dablool and Hamdoon's [21] findings match both Al Jurebi *et al.* [20] and the Kingdom of Saudi Arabia Ministry of Health [16] concluding that malaria transmission (Plasmodium falciparum) in Saudi Arabia is concentrated mainly in Jeddah, Jazan, and the Eastern areas. However, Plasmodium vivax and ovale transmission can be found in Jeddah, Eastern Province, Riyadh, and Jazan [21]. Moreover, the Jazan area is hyperendemic in malaria transmission despite other infections noted in the Western, Northern, and Lowland areas of Aseer [21]. In addition, Elagali *et al.*'s [4] research identified four geographic regions (Najran, Jazan, Bishah, and Al-Bahah) that exhibit malaria transmission in Saudi Arabia. Thus, the high-risk areas have remained four since 2017 and are located in the southern region of Saudi Arabia [4]. In this case, the high transmission of P. Falciparum was discovered in Najran and Jazan areas, whereas low to medium transmission of this vector was found in Bishah, Al-Bahah, and Aseer areas, which are located in the South-West and South regions of the country [4]. Moreover, low-level malaria transmission can be found in the Eastern and Northern areas of the country [4]. Therefore, Elagali *et al.* [4], the Kingdom of Saudi Arabia Ministry of Health [16], Al Jurebi *et al.* [20], and Dablool and Hamdoon [21] agree that the geographic distribution of malaria transmission reveals high occurrence in the Southern and South-western parts of the country, and low to medium occurrence in the Eastern and Northern parts. Also, there has been a noticeable change in case distribution from 2017 to 2022 among regions such as the Eastern region.

4.2. Differences According to Altitude

Altitude is a critical factor that influences malaria transmission in different regions. From a general perspective, malaria transmission tends to decrease with an increase in altitude because the Anopheles mosquito, known as the vector for the disease, prefers particular altitudes for survival [22]. This malaria parasite prefers lowlands and plains with warm temperatures. It is less prevalent in the highlands with higher altitudes due to the low temperatures and unfavourable environmental conditions for its survival [22]. Siya *et al.* [23] also note that malaria is more prevalent in lowland and plain regions with tropical climates than in highlands. Al-Mekhlafi *et al.* [5], Amer *et al.* [24], Garba [25], and Hawash *et al.* [26] agree that areas with high altitudes experience lower malaria transmission rates than regions of high altitudes, which shows the relationship between altitude and malaria transmission in Saudi Arabia. Amer *et al.* [24] discovered that the coastal plains of the Jazan region, located in a lower altitude area, recorded the highest malaria transmission rate (66.3%).

In contrast, the lowest malaria transmission rate (1.0%) was found in the high-altitude area of Al-Bahah. Thus, Amer *et al.* [24] confirm the general theory that high malaria transmission rates occur in low-altitude areas compared to the high-altitude regions. Garba [25] agrees with Amer *et al.* [24] by noting that lower altitudes, including valleys and coastal plains, experience higher malaria transmission because of the highly humid and warmer conditions that are conducive to the breeding of Anopheles mosquitoes. Al-Mekhlafi *et al.* [5] prove that the Jazan region has three distinct topographical zones that make it record high malaria transmission rates. These zones include the highland area of the Fafya Mountains, with an altitude of between 2500 and 3000 meters above sea level and a rainfall average of over 200 mm per year; the hill zone, with an altitude of between 400 and 600 meters above sea level and rainfall of less than 200 mm per year, and the coastal plain with a low altitude of below 400 meters above the sea level and a low sporadic rainfall, which increases the prevalence and transmission rates of malaria in the region [5]. Hawash *et al.* [26] also confirm that Jazan (Jizan) bears the highest malaria transmission burden due to its altitude, which ranges between 400 m and 2500 meters above sea level. In this case, high transmission rates occur in the coastal plains of Jazan, which have a low altitude compared to the other zones with high altitudes.

4.3. Differences between Rural and Urban Settings

Malaria transmission rates in urban settings are different from the infection rates in rural areas. Elagali *et al.* [4], Al-Mekhlafi *et al.* [5], and Larson *et al.* [27] agree that malaria transmission within the urban dwellings of Saudi Arabia is low in comparison to the rural areas. Al-Mekhlafi *et al.* [5] note that malaria has generally been known to be a rural problem as opposed to an urban issue because the urban areas have better sanitation, housing, and drainage systems that reduce the establishment of breeding grounds for mosquitoes that transmit malaria. Larson *et al.* [27] support Al-Mekhlafi *et al.*'s [5] statements by indicating that malaria incidences are generally lower within urban regions compared to rural places. However, they note that this difference is due to the fewer opportunities that enhance the reproduction of mosquito vectors in urban spaces, which leads to limited blood feeding by these parasites on humans Larson *et al.* [27].

Moreover, the KSA urban regions are unfavourable for the Anopheles mosquito due to the lack of plausible breeding grounds and the structural elements of urban houses, which often restrict the entrance of mosquitoes to houses, thus limiting transmission rates in these areas [27]. Elagali *et al.* [4] also support the research findings from Al-Mekhlafi *et al.* [5] and Larson *et al.* [27] by identifying the low transmission frequency of malaria in the Eastern and Northern parts of Saudi Arabia, especially the urban areas. On the other hand, Al-Mekhlafi *et al.* [5] also support the conclusions of Elagali *et al.* [4] and Larson *et al.* [27] by noting significantly high rates of malaria transmission among participants in rural areas (89.8%) compared to the subjects in urban dwellings (10.2%) based on their study. However, El-Eryani [19] predicts that there is a possibility for changes in the Anopheline vector distribution in the near future as the *An. stephensi* might invade Saudi Arabian land to become more predominant, hence urban area invasion, which contradicts the expected behaviour of the other Anopheline vectors. Therefore, Elagali *et al.* [4], Al-Mekhlafi *et al.* [5], and Larson *et al.* [27] prove the theory that urban spaces in Saudi Arabia record lower malaria transmission rates than rural areas in the current period.

4.4. The Seasonality of Malaria Infection in Saudi Arabia

The transmission of malaria in KSA exhibits a seasonal pattern. Elagali *et al.* [4], Abdalal *et al.* [7], Amer *et al.* [24], and Alanazi *et al.* [28] confirm that malaria transmission in Saudi Arabia depicts seasonality since the infection rates peak during the rainy season. Elagali *et al.* [4] posit that malaria transmission in Saudi Arabia illustrates seasonal patterns due to the high number of malaria infection cases reported in November, with its peak witnessed in January, a period that coincides with the rainy season and low temperatures. Abdalal *et al.* [7] agree with the findings of Elagali *et al.* [4] by asserting malaria transmission in Jazan exhibits seasonality since infections occur between October and April, with a notable peak in January, which corresponds to the rainy period in this region. Amer *et al.* [24] also concur with the findings of Elagali *et al.* [4] and Abdalal *et al.* [7] by noting that malaria transmission in Saudi Arabia is associated with the rainy season.

On the other hand, Amer *et al.* [24] and Alanazi *et al.* [28] attributed the seasonality of malaria transmission in Saudi Arabia to tourism and human movement into the country during religious festivities. According to Alanazi *et al.* [28], malaria transmission cases could be identified throughout the year, alongside an annual seasonality that peaked in September, while most cases occurred in June, August, and October. This seasonality is due to high rates of human travel into Saudi Arabia during these months [28]. Alanazi *et al.* [28] add that Indian, Saudi locals, African expatriates, and Pakistani nationals would be moving back to Saudi Arabia during these months after their time in summer vacation, which leads to high rates of malaria transmission since the period coincides with malaria peaking season when mosquito bites are high. Amer *et al.* [24] agree with the findings of Alanazi *et al.* [28] since they note that Saudi Arabia records a high number of malaria transmission cases with peaks between January and March, with the lowest rates recorded between May and July. However, Makkah and Madinah experience high transmission rates between August and October due to the high number of Muslim pilgrims that arrive in Saudi Arabia, which increases transmission rates due to imported cases [24]. Besides, workers moving into KSA from highly malaria-endemic nations contribute to the peaking of malaria transmission between August and October [24]. Therefore, Elagali *et al.* [4], Abdalal *et al.* [7], Amer *et al.* [24], and Alanazi *et al.* [28] confirm that malaria transmission in Saudi Arabia is seasonal and highly influenced by the rainy season and human movement into the country for work and religious activities. However, Islamic activities are bound with the Hijri Calander and, hence, are not bound by Gregorian month. Therefore, focused intervention should take place during this season due to human movement.

4.5. The Occupational Associations with Transmission

The transmission of malaria in KSA is linked to different occupational activities that enhance exposure to bites from infectious mosquitoes. Amer *et al.* [24], Almutairi *et al.* [29], WHO [30], Abdalal *et al.* [31], Shah *et al.* [32], Kibret *et al.* [33], and Alzahrani *et al.* [34] cite distinct occupational activities associated with malaria transmission in Saudi Arabia. First, Amer *et al.* [24], Almutairi *et al.* [29], and WHO [30] prove that religious occupation is associated with increased malaria transmission in Saudi Arabia. Amer *et al.* [24] note that Saudi Arabia records a high number of malaria transmission cases, with peaks between January and March and the lowest rates recorded between May and July. However, Makkah and Madinah experience high transmission rates between August and October due to the high number of Muslim pilgrims that arrive in Saudi Arabia, which increases transmission rates due to imported cases [24]. Similarly, Almutairi *et al.* [29] agree that religious occupation contributes to increased malaria transmission in Saudi Arabia. The participation in Umrah and Hajj by Muslim pilgrims contributes to the increased transmission of tropical diseases, including malaria, to the residents of Saudi Arabia [29]. In addition, the WHO [30] report indicates an increase in indigenous malaria transmission in Saudi Arabia in 2016 from below 100 annually in 2015 to 272 in 2016 [30]. Moreover, the confirmed imported and Indigenous malaria cases totalled 5382, with the majority (95%) being imported cases due to Hajj [30]. Second, Amer *et al.* [24], Abdalal *et al.* [24] [31] [32], and Shah *et al.* [32] prove that agricultural occupation is significantly associated with high malaria transmission in Saudi Arabia. Amer *et al.* [24] discovered that participants above 15 years recorded a high malaria infection rate due to their involvement with several activities, especially agriculture, which increased their chances of acquiring mosquito bites from Anopheles mosquitoes. Abdalal *et al.* [31] examined the relationship between engagement in agricultural activities and the increase in malaria infections in the Baish, Jazan region and confirmed that agricultural activities increase malaria transmission in Saudi Arabia. Thus, Abdalal *et al.* [31] found that farming had a significant contribution to the increase in malaria diagnoses among the study participants in Jazan. Shah *et al.* [32] also confirm that engagement in agricultural activities leads to an increase in human infectious diseases such as malaria. Third, Kibret *et al.* [33] and Alzahrani *et al.* [34] reveal that construction occupational activities increase susceptibility to malaria infections in Saudi Arabia. According to Kibret *et al.* [33], the construction of dams in Wadi Baysh, Jazan, presents a potential health hazard, which could intensify malaria transmission by presenting breeding grounds for infectious malaria species. Alzahrani *et al.* [34] examined the impact of irrigation systems on the rate of malaria transmission in Jazan, Saudi Arabia, with findings indicating that 53.2% of the total sample contained malaria anophelines larvae, which were detected from irrigation locations such as dams. Thus, Alzahrani *et al.* [34] prove that irrigation canals, reservoirs, and dams are linked to vector-borne diseases such as malaria in Saudi Arabia. Therefore, Amer *et al.* [24], Almutairi *et al.* [29], WHO [30], Abdalal *et al.* [31], Shah *et al.* [32], Kibret *et al.* [33], and Alzahrani *et al.* [34] prove that occupational activities, such as agriculture, religion, and construction as associated with increased malaria transmission in different regions of Saudi Arabia.

4.6. Malaria Parasite Species in Saudi Arabia

Elagali *et al.* [4], Amer *et al.* [24], Hawash *et al.* [26], and Alanazi *et al.* [28] agree that the main malaria parasite species in Saudi Arabia is *Plasmodium Falciparum*. Thus, Elagali *et al.* [4] noted that *P. Falciparum* was the most prevalent malaria species in Jazan compared to the other malaria vector species, indicating this parasite's dominance in the area. Elagali *et al.* [4] also discovered that central regions of the country, such as Ta'if, Riyadh, and Qassem, depicted dwindling levels of malaria species that ranged from the high of *P. falciparum* to the low of *P. ovale* and *P. vivax*. Similarly, Amer *et al.* [24] identified Plasmodium Falciparum as the most dominant malaria species in Jazan, Saudi Arabia, with a prevalence rate of 83.9%, whereas *Plasmodium vivax* and *Plasmodium malariae* recorded a 15.5% and 0.5% prevalence level respectively based on their study. Alanazi *et al.* [28] also concluded that *Plasmodium falciparum* was the most dominant malaria parasite in Saudi Arabia. Notably, *P. falciparum* had the highest frequency of infection, followed by *P. vivax [28]*. Elagali *et al.* [4] and Hawash *et al.* [26] also concurred that Plasmodium Falciparum had the highest predominance in causing malaria infections in the Jazan region. Therefore, Elagali *et al.* [4], Amer *et al.* [24], Hawash *et al.* [26], and Alanazi *et al.* [28] confirm that *P. falciparum* is the most dominant malaria species in Saudi Arabia.

4.7. The Prevalence and Number of Confirmed Cases over Time

The prevalence and number of confirmed malaria cases in Saudi Arabia over time is a fundamental topic that requires the presentation of the most accurate figures based on historical records. For this reason, the most accurate records for analysis of this topic included the Kingdom of Saudi Arabia Ministry of Health records and World Health Organization data. According to the Ministry of Health data, 2019 [35], the first malaria prevalence rate in Saudi Arabia was recorded in Jeddah when the government detected that approximately 35% of all outpatients in this region had malaria infections between the 1930s and 1940s. During this time, the government document reveals that malarial infection rates reached 160 individuals per every 1000 population annually within the Eastern Province of Saudi Arabia [35]. Between 1971 and 1981, approximately 2000 to 6000 malaria cases, either indigenous or imported, were identified annually through the Malaria Control Service [35]. However, these figures doubled in 1982 to nearly 15,000 malaria cases, with an average of between 10,000 and 18,000 reported infections annually until 1989 [35]. In the 1990s, the number of indigenous cases averaged one infection per every 1000 population. However, this number went high in 1998 when the Ministry of Health identified 36,139 indigenous malaria cases due to an outbreak that occurred in Aseer, Qunfudah, and Jazan [35]. In the early 2000s, the indigenous malaria cases were only confined to two parts of Saudi Arabia, including Jazan and Aseer [35]. However, 308 local transmissions were recorded in Jazan and Aseer in 2004 before a steady decline was witnessed from 2008 to 2015, with 29 to 83 cases being recorded annually in this period [35]. According to the World Health Organization [36], between 2008 and 2021, the number of indigenous malaria cases recorded in Saudi Arabia ranged from 0 to 272.

On the other hand, the report from the Ministry of Health [37] indicated a sharp increase in malaria cases from 2014 to 2016 due to the 5382 cases reported in this period. These reports are supported by the World Health Organization [38] report released in 2018, which indicated that 5382 malaria cases were identified in 2016, alongside 272 local cases in Aseer and Jazan areas. Therefore, the historical trends of malaria prevalence and cases reveal mixed findings from different governmental organisations despite showing data to prove that the incidences of malaria have been identified since the early twentieth century.

5. Task 3: High-Risk Populations and Hard-to-Reach Areas

5.1. Populations at Increased Risk of Malaria Based on Occupation

5.1.1. Farming

Amer *et al.* [24], Abdalal *et al.* [31], Shah *et al.* [32], Alzahrani *et al.* [34], Al-Shahrani *et al.* [39], Smith *et al.* [40], Lynch *et al.* [41], and Arinaitwe *et al.* [42] agree that particular types of occupations expose individuals to increased chances of malaria infection in Saudi Arabia. The first occupation is agricultural workers, which includes individual farmers in rural areas of Jazan and other regions who grow crops and expose themselves to frequent mosquito bites. Amer *et al.* [24] noted that economic activities such as farming exposed farmers to increased chances of getting mosquito bites that cause malaria. Abdalal *et al.* [31] proved that farmers are increasingly at risk of mosquito bites and malaria infection in Jazan Province. Shah *et al.* [32] also agree that farmers are highly exposed to malaria due to the working conditions, such as bushy areas that make them vulnerable to infectious mosquito bites. On the other hand, Al-Shahrani *et al.* [39] noted that land reclamation for agricultural activities increases the risk of human mosquito bites and malaria, especially among farmers who work in such areas. In addition, Lynch *et al.* [41], Smith *et al.* [40], and Arinaitwe *et al.* [42] discovered that farmers with records of travel outside Saudi Arabia exposed themselves to increased malaria transmission due to imported cases. Thus, Amer *et al.* [24], Abdalal *et al.* [31], Shah *et al.* [32], Alzahrani *et al.* [34], Al-Shahrani *et al.* [39], Smith *et al.* [40], Lynch *et al.* [41], and Arinaitwe *et al.* [42] prove that occupational activities such as agriculture are associated with increased malaria transmission in different regions of Saudi Arabia.

5.1.2. Construction

Kibret *et al.* [33], Alzahrani *et al.* [34], Mary *et al.* [43], and Johansen *et al.* [44] confirm that construction occupational activities increase susceptibility to malaria infections in Saudi Arabia. According to Kibret *et al.* [33], the construction of dams in Wadi Baysh, Jazan, presents a potential health hazard, which could intensify malaria transmission by presenting breeding grounds for infectious malaria species. Similarly, Alzahrani *et al.* [34] confirm that irrigation canals, reservoirs, and dams are linked to vector-borne diseases such as malaria in Saudi Arabia. Alzahrani *et al.* [34] examined the impact of irrigation systems on the rate of malaria transmission in Jazan, Saudi Arabia, with the findings revealing that 53.2% of the total sample contained malaria anophelines larvae, which were detected from irrigation locations such as dams. Mary *et al.* [43] also examined the relationship between the construction of dams and the increase in malaria transmission. They discovered that large dams are catalysts for the high annual malaria transmission in different regions. Moreover, Johansen *et al.* [44] confirm that high malaria infections are found among males working in construction areas. Therefore, Kibret *et al.* [33], Alzahrani *et al.* [34], Mary *et al.* [43], and Johansen *et al.* [44] confirm that construction as an occupation increases the risk of malaria infection among workers in Saudi Arabia.

5.1.3. Travelers and Expatriates

This occupational category also presents significant risks of malaria infection since travellers from malaria-endemic countries that arrive in Saudi Arabia are highly likely to transmit malaria to the locals through mosquito bites. Kitro *et al.* [45] note that expatriates without prior experience living in tropical regions identify the increased chances of contracting infectious diseases. According to Chen and Hamer [46], expatriates can be classified into long-term types of travellers, such as corporate employees, diplomats, and retirees. In terms of definition, expatriates constitute a subsection of long-term travellers living away from their home nations for occupational reasons [46] [47]. In addition, expatriates are often exposed to infections in the host countries since they have to utilise local infrastructures that expose them to hazards in these nations [46] [47]. Thus, expatriate travelling is a significant contributor to the global spread of infectious diseases. Hence, this category of travellers needs proper health preparations when planning overseas trips [48] [49]. The current study [50] on the relationship between travellers/expatriates and transmission of malaria in the Kingdom of Saudi Arabia reveals that visitors arriving from malaria-endemic regions contribute to a high number of transmissions in the country. According to El-Marky *et al.* [50], travellers arriving in Makkah, Saudi Arabia, present a significant risk of malaria transmission since most come from subtropical and tropical countries, such as Yemen and India, that are malaria-endemic. These visitors come to Saudi Arabia to perform Umrah and Hajj annually, leading to increased malaria transmission opportunities due to interaction with the locals [50]. In addition, the millions of expatriates who arrive in the Makkah region for job opportunities act as carriers of malaria when they come into the country, thus increasing the rates of imported malaria transmission [50].

On the other hand, Saudi Arabian nationals who travel to endemic countries transmit a return to the country and encourage malaria transmission [50]. Alanazi *et al.* [28] also support the conclusions of El-Marky *et al.* [50] by noting the increased risks related to the re-introduction of malaria in Saudi Arabia's Eastern Province due to the increased national and internal travelling to endemic areas. Therefore, Kitro *et al.* [45], Chen and Hamer [46], Chen *et al.* [47], Shepherd and Shoff [48], Fonseca *et al.* [49], and Al-Malky *et al.* [51] agree there is a positive association between high malaria transmission and the increase in travellers and expatriates from malaria-endemic regions.

5.2. Populations at Increased Risk of Malaria Based on Geographic Location

According to the Kingdom of Saudi Arabia Ministry of Health [35], the country's first category of vulnerable populations to malaria attacks comprises the people living in coastal areas. Notably, the country's coastal areas had previously recorded high levels of malaria transmission due to increased floods [35]. Moreover, these regions experience high rainfall of over 100 mm annually, leading to high malaria transmission levels through the *Anopheles arabiensis* vector [35]. The second population at increased risk of contracting malaria is individuals in lowlands or plains in Saudi Arabia. In this case, the plateaus have originally experienced high levels of mosquito transmissions alongside epidemics [35].

Moreover, the third vulnerable population to malaria infections includes families living near mountainous areas below 2000 meters [35]. These regions pose more significant risks to malaria infections than other parts of Saudi Arabia because of high rainfall that ranges from 400 mm to 800 mm per annum [35]. The fourth vulnerable population to malaria infections includes families staying in border regions of Saudi Arabia [35]. Thus, the malaria ecotype in these regions is highly infectious due to the imported malaria cases from the migrants that arrive in the country.

5.3. Populations at Increased Risk of Malaria Based on Demographics

According to the Kingdom of Saudi Arabia Ministry of Health [37], the most vulnerable cases of malaria infection include children above the age of 10 in most of the endemic zones. Moreover, the Kingdom of Saudi Arabia Ministry of Health [37] proves that ages above 15 have increased risks of malaria infections. Therefore, the Saudi Arabian government identifies children in the endemic zones as the most vulnerable populations to malaria infections.

5.4. Populations at Increased Risk of Malaria Based on Lifestyle

Lifestyle habits also lead to increased risks of malaria infection. For instance, immigrants who arrive in Saudi Arabia for annual religious activities are at increased risk of acquiring malaria infections due to interactions with people from other malaria-endemic countries Almutairi *et al.* [29]. Similarly, families that depend on farming as the primary source of income and lifestyle have increased chances of malaria infections Amer *et al.*, [24]. Therefore, tourism and farming lifestyles expose individuals to high chances of malaria infections in Saudi Arabia.

5.5. Populations at Increased Risk of Malaria Based on Health-Seeking Behaviours

Populations that travel outside Saudi Arabia in search of medical treatment in malaria-endemic zones have increased their chances of acquiring malaria infections. Moreover, individuals who travel to malaria-endemic zones in Saudi Arabia, such as Jazan, in search of treatment have increased chances of malaria infections [35]. Therefore, health-seeking behaviours, such as travelling to seek treatment in malaria-endemic zones and countries, increase the risk of malaria infections.

6. Task 4: Last Indigenous Malaria Cases and Foci in the Country

6.1. The Last Indigenous Cases and Last Malaria Foci in the Country in the 5 Years

The number of indigenous cases has changed, as revealed in **Table 3**. Elagali *et al.* [4] noted that the confirmed malaria cases reported in Saudi Arabia were either local or imported. However, despite no indigenous malaria cases, Aseer and Jazan showed introduced cases, while the rest of the populations examined showed that infections originated from imported cases [4]. In addition, the World Health Organization [51] revealed that indigenous malaria cases reduced from 272 in 2016 to 18 in 2019. The report [51] indicates that this massive reduction in indigenous cases was attributed to continued vigilance by the Ministry of Health in Saudi Arabia, which led to the effective diagnosis and treatment of each imported case [51]. The reduction in the number of Indigenous cases in the last five years is also confirmed by the World Health Organization [52], which indicates that Saudi Arabia achieved its goals of reducing the number of Indigenous cases from 10 to 99 in 2019 to less than 10 in 2022. These figures also show zero indigenous malaria cases in 2021 and 2022 [52]. Thus, the World Health Organization [52] proves that Suriname and KSA, which recorded 38 and 104 cases in 2019, attained zero indigenous cases from 2021 to 2022. Gasimov [53] also confirms that the KSA recorded zero Indigenous cases in 2022 after recording similar figures in the previous years. Notably, Gasimov [53] also provides a list of indigenous cases over the last five years by indicating that KSA recorded 38 cases in 2019, 83 in 2020, 0 in 2021, and 0 in 2022 [53]. Therefore, these sources prove that the number of indigenous cases in Saudi Arabia over the last five years has been declining because of the malaria interventions enforced by the KSA government.

Elagali *et al.* [4], Abdalal *et al.* [7], and WHO [38], only a few foci could be identified in the last five years. For instance, the WHO [38] indicated over 100 active malarial foci were discovered within the South-Western parts of Saudi

Arabia in 2018. WHO [38] also clarifies that this region's Jazan and Asir areas recorded 113 active malarial transmission foci in 2018. Similarly, Abdalal *et al.* [7] confirmed the presence of active transmission foci in the Jazan area in 2022. In addition, Elagali *et al.* [4] assert that the active transmission foci existed in the South-Western parts of Saudi Arabia, such as Najran, Jazan, Aseer, and Taif. Thus, Elagali *et al.* [4] prove that the active transmission foci for *P. falciparum* were identified in Najran and Jazan. Moreover, Elagali *et al.* [4] posit that Bishah, Al-Bahah, Aseer, and Taif are other south-western areas in KSA that recorded active transmission foci with varied levels of malaria transmission during the period. For this reason, Elagali *et al.* [4], Abdalal *et al.* [7], and WHO [38] prove that the active malaria transmission foci in the last five years have varied despite the target areas being in the South-Western regions of KSA.

6.2. Specific Actions to Eliminate Malaria in the Last Three Foci

6.2.1. Detection

According to a report by the Saudi Arabia Ministry of Health [35], the government of Saudi Arabia has adopted active and passive detection measures since 2004 through Primary Healthcare Centre networks and the corporate private sector. Thus, the detection system requires notification within 24 hours to the malaria centre teams using WhatsApp, facsimile, or the 977-text messaging option [35]. This notification method after detection is based on a network collaboration with the Health Information Systems and Integrated Disease Notification System from KSA's Ministry of Health [35]. This collaboration enhances the immediate transmission of the detected malaria case in the web-based database system [35]. Therefore, malaria detection occurs through collaboration between the Saudi Arabian government and the community workers who provide notifications of suspected cases.

6.2.2. Entomological Investigation

Case investigations occur in a span of three days upon receipt of notification from the reporting centres. Therefore, the malaria investigative teams begin to examine the case origin by analysing the travel and case histories and employing a screening exercise within a radius of 500 m of the place where the malaria case was detected in the field [35]. During this investigation, the malaria-positive cases are transported to nearby health facilities by the mobile teams to get immediate treatment based on the legal requirements of the KSA [35]. Notably, the investigative team carries out entomological investigations in the neighbourhood of the detected case before implementing the vector control measures [35]. The investigation team also uses the investigation form to record all the details of the case detected and community dynamics before sending the data through email or facsimile by the Ministry of Health's malaria department within 72 hours of the report [35]. Therefore, malaria investigations in Saudi Arabia are conducted by collaborating with health professionals and community workers in the neighbourhoods.

6.2.3. Actions to Eliminate

The Saudi Arabia Ministry of Health report [35], El Hassan *et al.* [54], World Health Organization [55], and Khairy *et al.* [56] agree that the government of Saudi Arabia has employed different action plans to eliminate detected malaria cases. According to the Saudi Arabia Ministry of Health report [35], the first method used by the government to eliminate malaria cases includes environmental or mechanical programs. This action plan involves the elimination or reduction of the breeding places of mosquitoes using mechanical means, such as drying stagnant pools of water and opening drainage systems to allow the free flow of water [35]. The second method includes chemical spraying, which involves using modern mosquito elimination chemicals sprayed in the places where detection occurred to control further mosquito larvae development in the breeding grounds [35]. In addition, the spaying exercise is conducted within the area of case detection to avoid further breeding of mosquitoes in the area [35]. The third fundamental step taken by Saudi Arabian health officials is to use larviciding plant oil [35]. This method is among the most recently employed by the government to control the further breeding of mosquitoes in the area of detection [35]. The other action plan includes using insecticides, such as pyrethroids, that are applied on treated bed nets [35].

On the other hand, El Hassan *et al.* [54] note that local authority through the Ministry of Health in Jazan Province employs active case detection, applies practical approaches for surveillance and uses modern and advanced epidemiological apparatus to control further malaria transmission in the identified area. According to the World Health Organization [55], the local authority through the Ministry of Health in Saudi Arabia should employ detection of infection activities, drainage of the last residual foci sinks, and prevention of imported new infections. Khairy *et al.* [56] examined the best action plans to employ to eliminate malaria transmission. They discovered that the employment of treatment measures in health facilities ranked highest among the participants' priorities. Notably, seeking treatment within the first 24 hours of infection could increase the efficacy of eliminating the disease since it reduces the chances of spreading through mosquito bites [56].

Moreover, indoor residual spraying emerged as a significant elimination method, as did the use of anti-mosquito spraying and nets [56]. El Hassan *et al.* [54] also indicate that the Saudi Arabian healthcare system currently uses advanced detection systems such as the Convolutional Neural Network to identify malaria cases. This represents an improved detection method to enable hotspot mapping. In addition, El Hassan *et al.* [54] highlight the need for active detection systems, which enable community health workers to respond quickly to the identified cases within the community. However, the Saudi Arabia Ministry of Health [35] recommends using space spraying, which involves routine application of insecticides with modern and effective chemicals to control the breeding of mosquitoes. This method has been useful in KSA by helping to effectively eliminate malaria cases within the neighbours' houses and potential outdoor places, which improves the rate of community elimination of this vector within the community [35]. Therefore, the Saudi Arabia Ministry of Health report [35], El Hassan *et al.* [54], World Health Organization [55], and Khairy *et al.* [56] identify chemical, mechanical, and strategic environmental programs to eliminate malaria in KSA (**Figure 2**).

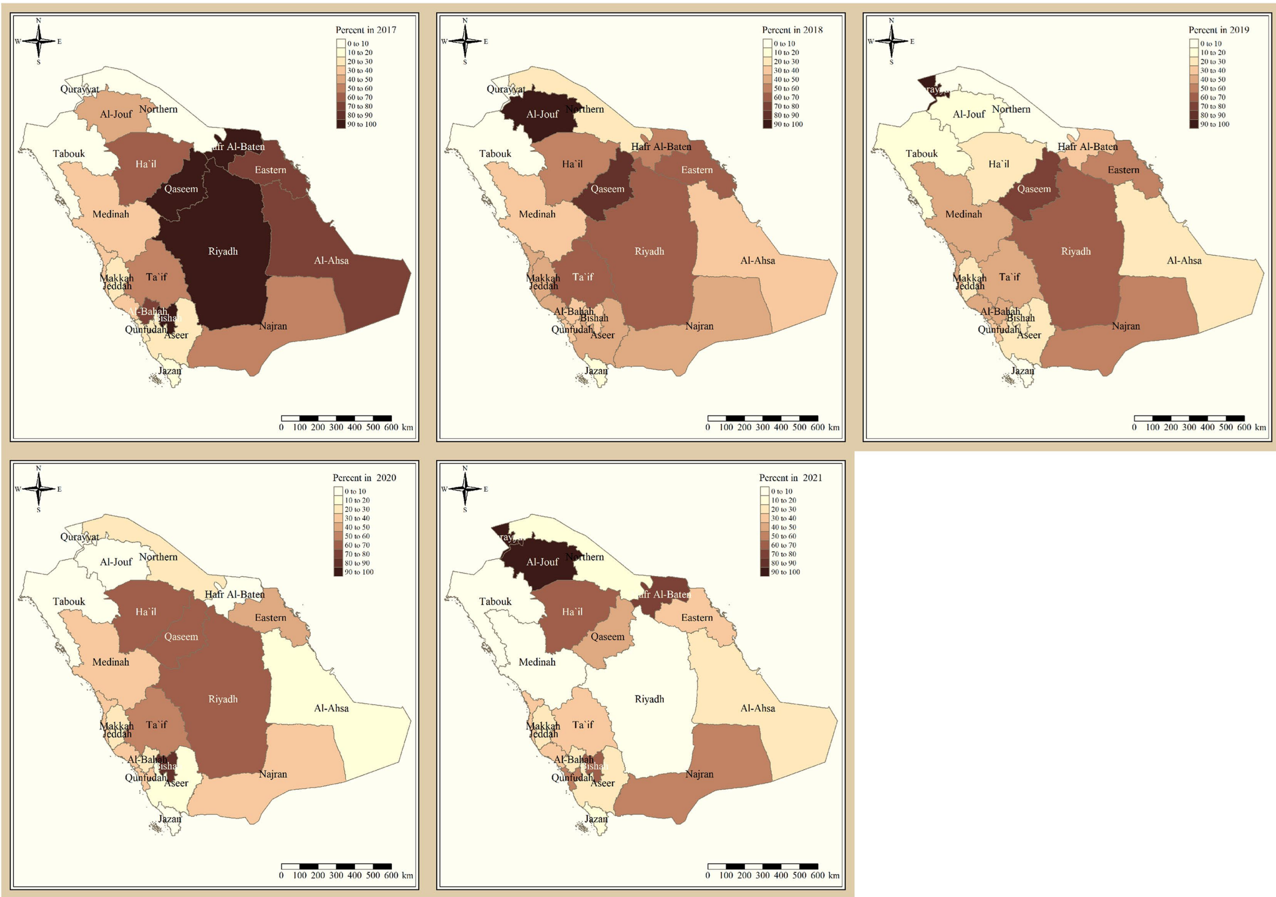

Figure 2. Map of Malaria Transmission Foci. Map 1 above shows that the active transmission foci include the South-Western parts of Saudi Arabia in the regions of Jazan and Aseer. Source: [4].

7. Task 5: Entomological Aspects of Malaria Transmission

7.1. Geographic Distribution of Principal and Secondary Anopheline Vector Species in Saudi Arabia

The Saudi Arabian country has both primary and secondary Anopheline vector species that cause malaria infections in the population. According to the Saudi Arabia Ministry of Health report [35], the government identifies 17 Anopheles species that are recorded in the history of Saudi Arabia. However, the report shows that four out of the 17 are the principal Anopheles mosquitoes in the region. In this case, the four primary vectors that cause malaria in Saudi Arabia include *An. arabiensis*, *An. stephensi*, *An. sergentii*, and *An. superpictus* [35]. On the other hand, the report [35] indicates that the geographic distribution of these dominant vectors includes *An. stephensi* is rampant in the Eastern region, whereas the *An. sergentii* is prevalent in the West and Central regions [35]. The *An. superpictus* is found mainly in the Northern parts, whereas the An. Arabiensis is commonly found in south-western parts of Saudi Arabia [35]. Additionally, *An. sergentii* is featured as the most dominant and rampant vector across Saudi Arabia and is considered the most significant transmitter of malaria in the southwest regions [35].

Moreover, the An. Arabiensis is also concentrated mainly in the south-western part of Saudi Arabia, which has a considerable ecological range [35]. On the other hand, the secondary malaria vectors in Saudi Arabia include *An. Azaniae*, *An. Coustanti*, *An. Pharoensis*, *An. Cinereus*, *An. Pharoensis*, and *An. pulchrrimus* among others [35]. According to Coleman *et al.* [57], the *Anopheles superpictus* and *An. stephensi* are the most dominant malaria vectors in Saudi Arabia and are primarily distributed in the Eastern and Northern regions. Conversely, Alzahrani *et al.* [34] also confirm that the primary malaria vector in Saudi Arabia is Anopheles Arabiensis despite the existence of other species that present significant malarial threats, such as *Sergentii*, *Dthali*, *Fluvitilis*, *and Stephensi*. Therefore, the geographic distribution of Anopheline vectors includes the Western, Eastern, South-western, and Central parts of Saudi Arabia.

7.2. Biological Behaviour

The Anopheline vector species exhibits particular biological behaviours, which makes it highly infectious in humans, according to Fornadel *et al.* [58], Tirados *et al.* [59], Githeko *et al.* [60], Kulkarni *et al.* [61], and Mahande *et al.* [62]. According to Fornadel *et al.* [58], the Anopheline vector has a preferred feeding behaviour that makes it distinct from other species of mosquitoes. In this case, the *Anopheline mosquitoes* depict endophilic behaviours that make them highly dangerous for transmitting malaria in Saudi Arabia [59]. This type of vector is associated with indoor behaviours such as resting within houses [59]. The unsuitability of outdoor areas makes it easy for the *Anopheline mosquitoes* to develop the behaviour of resting indoors, which makes them have a prolonged period and opportunities to bite people [60].

Moreover, the endophilic nature of the Anopheline mosquito could be due to the climate, which causes the *Anopheles arabiensis* to rest indoors during cool weather [61]. On the other hand, the *Anopheline mosquitoes* have zoophilic behaviours, which make them attracted to cattle by feeding on their blood [61]. According to Mahande *et al.* [62], Anopheles *arabiensis* has zoophilic tendencies since it is more likely to be found in cattle sheds than in human houses. Moreover, Habtewold *et al.* [63] support the findings by Mahande [62] by indicating that Anopheles *arabiensis* has a significantly lower Human Blood Index than the other species and has a preference for warm-blooded animals and cattle. Pates [64] also confirms that *Anopheles gambiae* is zoophilic, which makes it prefer feeding on cattle and prevalent in cattle sheds. Mahande *et al.* [62] also assert that Anopheles *arabiensis* has higher exophilic behaviour compared to *Anopheles gambiae*. Therefore, Fornadel *et al.* [58], Tirados *et al.* [59], Githeko *et al.* [60], Kulkarni *et al.* [61], and Mahande *et al.* [62] prove that the Anopheline mosquito vector species has zoophilic, endophilic, and exophilic behaviors.

7.3. Efficacy in Transmitting the Local Species of Malaria Parasites

The efficacy of the Anopheline vector is based on its ability to target local species of malaria parasites in Saudi Arabia, and it could depend on environmental factors, parasite species, and vector species. Al-Mekhlafi *et al.* [5], the Saudi Arabia Ministry of Health report [35], and the World Health Organization [65] present diverse opinions on the issue of efficacy in the transmission of local malaria parasite species. According to Al-Mekhlafi *et al.* [5], the primary Anopheline vector in Saudi Arabia is the *Anopheles arabiensis* despite the existence of other competent vectors, such as *Anopheles arabiensis*, *An. dthali*, *An. sergentii*, and *An. superpictus*. The Saudi Arabia Ministry of Health [35] notes that *An. arabiensis*, *An. stephensi*, *An. sergentii*, and *An. superpictus* are responsible for the transmission of local parasites, such as Plasmodium Falciparum, the major malaria species that causes malaria disease in Saudi Arabia, alongside Plasmodium vivax. On the other hand, the World Health Organization [65] indicates that *Anopheles stephensi* is an example of a mosquito species that can transmit P. falciparum and p, vivax parasites and thrives in urban environments. Therefore, Al-Mekhlafi *et al.* [5], the Saudi Arabia Ministry of Health report [35], and the World Health Organization [65] identify *Anopheles arabiensis* as the primary malaria vector responsible for the transmission of Plasmodium Falciparum alongside Plasmodium vivax, which constitutes the significant species of malaria that causes malaria disease in Saudi Arabia.

Moreover, the WHO defines the efficacy of transmission under a term known as "Receptivity", which is the "degree to which an ecosystem in a given area at a given time allows for the transmission of Plasmodium spp. from a human through a vector mosquito to another human" [66]. Also, they add the note, "This concept reflects vectorial capacity, susceptibility of the human population to malaria infection, and the strength of the health system, including malaria interventions. Receptivity depends on vector susceptibility to particular species of Plasmodium and is influenced by ecological and climatic factors" [66]. Based on the statements mentioned above, there is an apparent deficit in data analysis, either quantitative or semi-quantitative (qualitative) estimation, to assess the receptivity in practice according to the updated Malaria Journal 2022 [67]. However, based on the epidemiological data collected through the investigation forms used by the Ministry of Health [35], there is a crucial need to work on the quantitative estimation of receptivity through the basic reproductive number (R0), controlled reproductive number (Rc) and effective reproductive number (Re) to guide the program through practical usage of receptivity assessment [67].

7.4. Seasonal (or Perennial) Patterns of Vector Density

According to Khater [68], Gillies [69], WHO [70], and WHO [71], the *Anopheles arabiensis* remains the only malaria vector species found beyond KSA since it extends to other nations in the Arabian Peninsula, Yemen, and other parts of Africa. According to the studies conducted by Abdoon and Alsharani [72], Abdullah and Merdan [73], and Al-Ghamdi *et al.* [74] the Anopheles arabiensis is the most dominant malaria vector species alongside *Anopheles gambiae* across various stages of development [72]-[74]. Al-Ahmed *et al.* [75] performed research in Al Bahah, KSA, to determine the density and ecological environments of mosquitoes in the region. The results indicated 19 Anopheline vector species, including arabiensis, d'thali, cinereus, and subpictus, among others. Regarding seasonality, Al-Ahmed *et al.* [75] noted that adult mosquitoes were present across the year despite a record of different magnitudes based on the existing climatic conditions [75]. Thus, the population density of adult Anopheles mosquitoes of different species increased gradually from April to May as the temperature increased and peaked in June at 29˚C with monthly rainfall averaging 10 mm [75]. However, this density in the vector population significantly reduced from August to September as it reached the minimum levels in November as the temperatures averaged approximately 18˚C [75]. Similarly, Alahmed [76] notes that the number of Anopheles vector species larvae in the Eastern region of Saudi Arabia was high, with no correlation between pH and mosquito vector population. Also, adult Anopheles vector species were present across the year despite the differences in densities according to the current climatic conditions [75]. Therefore, the seasonal patterns of the Anopheline vector density revealed that the rainy season represents the time when the species are most prevalent due to the existence of breeding grounds and suitable temperatures for reproduction.

7.5. Insecticide Resistance Status

The historical analysis of the insecticide resistance status by the Anopheles vector reveals that despite the progressive resistance of particular insecticides, the KSA has often developed better chemicals to overcome the problem. According to the Saudi Arabia Ministry of Health [35], the *Anopheles stephensi* vector developed resistance to DDT pesticides in 1955, leading to the resistance of Dieldrin in 1957, which was caused by this vector in the same location. Moreover, Camara *et al.* [77], Awolola *et al.* [78], Dabire *et al.* [79], Ochomo *et al.* [80], and Djègbé *et al.* [81] also recognize that the resistance persisted by 1970 when the *Anopheles Stephensi* vector resisted both DDT and Dieldrin in the northern and central parts of KSA. According to Vatandoost *et al.* [82], Vatandoost *et al.* [83], Davari *et al.* [84], Hanafi-Bojd *et al.* [85], Zoh *et al.* [86], Davari *et al.* [87], Abai *et al.* [88], Hasasan *et al.* [89], Vatandoost *et al.* [90], Soltani *et al.* [91], and Lak *et al.* [92], the resistance led to the development of fenitrothion and malathion in 1987 and 1990 respectively. Between 2002 and 2010, deltamethrin was usable in Jazan alongside Deltamethrin and Lambdcyhlothrin [35]. However, temephos was resisted by several Anopheles vector species in 2006 before compatibility was achieved in 2012. On the other hand, Enayati *et al.* [93], Soltani *et al.* [94], Omrani *et al.* [95], Omrani *et al.* [96], Omrani *et al.* [97], Koffi *et al.* [98], N'Guessan *et al.*

[99], Strode *et al.* [100] indicate that the application of pyrethroid insecticides promoted the widespread resistance by the Anopheles vectors. In turn, Churcher *et al.* [101] and Chandre *et al.* [102] confirm that the resistance led to the ineffectiveness of the mosquito nets treated by the pyrethroid insecticide. Thus, the Anopheles vector species has exhibited resistance over time despite the efforts by the KSA to improve compatibility with the insecticides. (**Figure 3**)

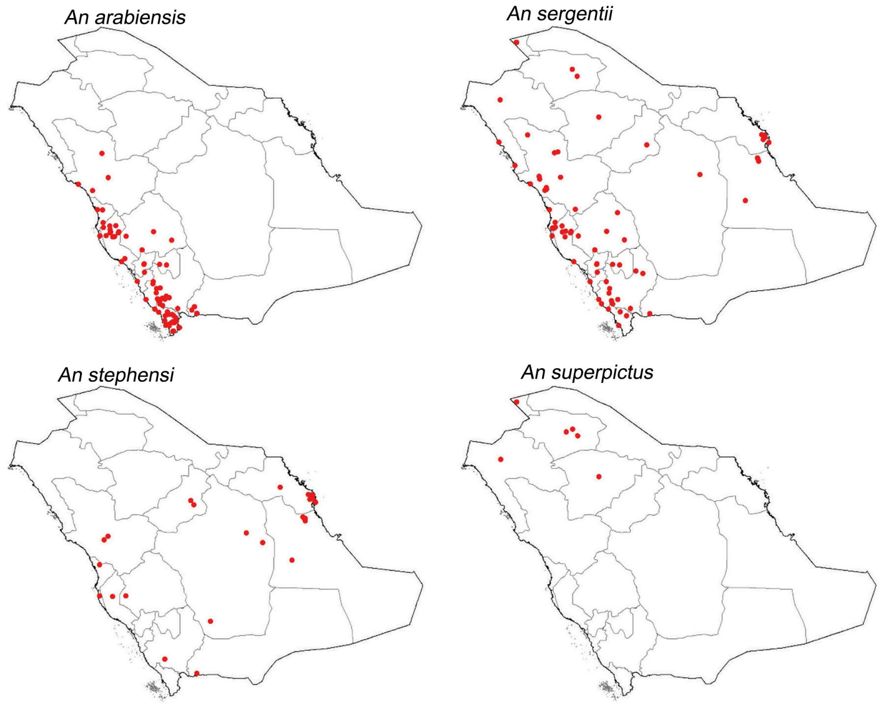

Figure 3. Current distribution of the main malaria vectors (2019). Source: [35].

8. Results

Malaria was recognized in Saudi Arabia in the 1940s; the Saudi Arabia Malaria Control Program was established in 1948, and is perhaps one of the most significant public health achievements in the Kingdom over the past 40 years. The challenge facing the country now is to maintain malaria control in areas where malaria cases have been recorded while keeping the rest of the country malaria-free.

9. Conclusion

Malaria infections in the KSA have been a problem since the early 1930s, when the government enforced different measures to deal with the problem. Malaria epidemiology in Saudi Arabia is variable since the trends depict variation from one region to another and location to location within the same region. In addition, epidemics in Saudi Arabia have been caused by human movements into the country for job opportunities, tourism, or religious activities, which increase the cases of malaria transmission through mosquito bites from infected individuals. Moreover, several methods to detect, investigate, and eliminate malaria infections in the KSA have been employed by the Saudi Arabian government over time. The most affected regions in Saudi Arabia are the Jazan and Aseer areas due to the abundance of the Anopheline vector through several environmental and human factors. However, the continued enforcement of measures by the Saudi Arabian Ministry of Health will enable the government to achieve zero infections across all regions of the country in the future if it is being carried out efficiently.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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