Scientific Research Publishing

Advances in Infectious Diseases, 2022, 12, 758-775
https://www.scirp.org/journal/aid
ISSN Online: 2164-2656
ISSN Print: 2164-2648

COVID-19 and Malaria: A Comparative Study of Epidemiology, Burden, and Challenges

Hamid H. Hussien

Department of Mathematics, College of Science and Arts, King Abdulaziz University, Rabigh, Saudi Arabia
Email: hamid128@yahoo.com

How to cite this paper: Hussien, H.H. (2022) COVID-19 and Malaria: A Comparative Study of Epidemiology, Burden, and Challenges. *Advances in Infectious Diseases*, **12**, 758-775.
https://doi.org/10.4236/aid.2022.124053

Received: October 18, 2022
Accepted: November 26, 2022
Published: November 29, 2022

Abstract

Introduction: Assessing global health status includes tracking illness, disability, and mortality. Environmental and social factors as well as health initiatives impact people's health. Assessing health outcomes in terms of mortality and morbidity, which are included in the global disease burden, is critical for monitoring progress in development and health, as well as for selecting how to allocate available resources effectively, to achieve positive health outcomes. Studies on the epidemiology, burden, and challenges of COVID-19 and malaria remain scarce. There isn't much information on how malaria susceptibility and immune response are affected by co-infection with COVID-19, and vice versa. This article highlights the commonalities between malaria and coronavirus disease 2019 (COVID-19), reviews the epidemiology, burden, and challenges of each, and outlines how global health authorities have responded to the burden and challenges. **Methods:** We used The World Health Organization Disease Situation Dashboard as the primary resource for obtaining information on malaria and COVID-19. The World Malaria Reports for 2020 and 2021 were used as the primary sources for the statistics on malaria. Descriptive statistics were used to analyze the data collected. **Results:** The number of malaria deaths and cases has decreased significantly worldwide since 2000, but the African region continues to bear the greatest burden of malaria. The highest number of deaths due to COVID-19 occurred in the Americas, followed by Europe. The burden is lighter in Southeast Asia, the Eastern Mediterranean, the western Pacific, and Africa. There has been a decline in the number of deaths caused by COVID-19 in areas where malaria is endemic. Further, the COVID-19 pandemic has increased the burden of malaria in Africa. **Conclusion:** Public health authorities should consider taking necessary preventive measures to fight malaria and COVID-19 in a timely manner and ensure continuous healthcare for those who are affected by these diseases.

Keywords

COVID-19, Malaria, Epidemiology, Disease Burden, African Region

1. Introduction

Global health goals aim to promote health and prevent and treat diseases across countries worldwide [1]. Infectious disease outbreaks and pandemics have devastating effects on health systems, especially with overlapping common symptoms between diseases. Within the last decade, malaria has been brought under control via therapies that have proven to be extremely effective all over the world. The COVID-19 pandemic, on the other hand, has the potential to stress and disrupt existing health care systems [2]. As a result, countries where malaria is a prevalent disease should seriously consider testing all possible cases for both malaria and COVID-19. COVID-19 and malaria epidemics can devastate low- and middle-income countries. Due to insufficient infrastructure, a shortage of health staff, and limited financial resources, such countries have fragile healthcare systems. Preparedness is essential to avoid the indirect short- and long-term consequences of the COVID-19 pandemic [3] on malaria control programmes and healthcare systems in areas where the two diseases overlap. The ongoing coronavirus disease (COVID-19) pandemic represents an obstacle in combating malaria as both diseases may have similar signs and symptoms [2]. This makes it difficult to differentiate between the diseases, especially in tropical areas. For these reasons, this comparative study was designed to highlight the epidemiology, burden, and challenges of malaria and COVID-19. We shed light on the climatic elements that play a key role in the spread of these diseases, in addition to the role of vaccinations for malaria and COVID-19. Frontline clinicians and public health officials can look into the current situation and future prospects of a COVID-19-malaria scenario and its effects.

2. Data Source and Statistical Methods

The data for this analysis were collected from public data sources. The World Health Organization (WHO) Disease Situation Dashboard is the primary source of information on malaria and COVID-19. The malaria statistics were sourced from the World Malaria Reports for 2020 and 2021. The variables of the study represent the burden of each disease (the number of cases and deaths from malaria during the period 2000-2022, and the number of cases and deaths from COVID-19 as of April 29, 2022). The data was presented as numbers and proportions and categorical data was presented as graphs. The differences between the characteristics were compared using the percentage, the mean and the standard deviation. The data were analyzed according to the WHO geographic regions: the African region, the Americas, the Eastern Mediterranean, Europe, Southeast Asia, and the Western Pacific.

3. Epidemiology of COVID-19 and Malaria

3.1. COVID-19 Epidemiology

The COVID-19, a contagious disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pathogen [4], affects many organs and sys-

tems in the body, but primarily the lungs and other parts of the respiratory system. It is considered one of the most lethal viruses, till date and due to the risks and threat it poses, WHO declared the highest level of global readiness and has set challenges and limits to curb and prevent the spread of infection [5]. The virus spreads directly from one person to another in three ways: 1) breathing in the air near an infected person who is exhaling small droplets and particles that carry the virus; 2) being sprayed or splashed with droplets produced during coughing by an infected person, on one's eyes, nose, or mouth; or 3) touching one's eyes, nose, or mouth with infected hands. The disease may present as mild to severe symptoms or simple affected people may remain asymptomatic. The incubation period is between one and 14 days, with an average incubation of five-six days. In approximately 97% of people, symptoms are presented around an average of 14 days [6].

People over the age of 65 years and those with certain underlying medical comorbidities are more prone to serious illness due to COVID-19. Apart from getting vaccinated, wearing a mask, and washing hands are important non-pharmaceutical interventions in preventing COVID-19. People can reduce the risk of infection by avoiding congested areas, enclosed spaces, and close contact with other infected persons. The basic reproduction of the virus, the mechanisms and regulation of RNA translation, replication and transcription, and the virus's initial transmissibility (R0), that ranged from 2.0 to 4.0 were investigated. There was underreporting and under detection of cases during the early stages of the outbreak in Wuhan, China [7]. The COVID-19 was declared a pandemic on March 11, 2020, after more than 118,000 cases were reported in 114 countries. By April 2, 2020, more than 52,000 people had died, and 1 million cases were reported in more than 204 countries and territories worldwide [8].

Two years after the beginning of the pandemic, the disease has spread to over 200 countries, resulting in many confirmed illnesses and deaths, as well as widespread panic and mental health concerns [9]. The pandemic is a severe threat to humanity [10], in terms of its negative impact on people's quality of life and well-being, markets, and economies. It affects all demographics. The risk of severe COVID-19 increases with age and underlying medical comorbidities, such as hypertension, diabetes, cardiovascular disease, chronic respiratory diseases, and cancer [11].

The SARS-CoV-2 has evolved into many COVID-19 variants over time. Vaccines, therapeutic medicines, diagnostic tools, and other public health and social measures can all have an impact on ease of spread of a disease and its severity. Some of the COVID-19 variants of concern that were published by WHO are as follows:

1) 1.1.7 (Alpha), Date of designation December 18, 2020
2) 1.351 (Beta), Date of designation December 18, 2020
3) 1 (Gamma), Date of designation 11-Jan-2021
4) 1.617.2 (Delta), Date of designation 11-May-2020
5) 1.1.529 (Omicron), Date of designation is 26-Nov-2021

At the time of this analysis, the world was suffering from the impact of the Omicron wave, a novel variant of SARS-CoV-2 that circulated in South Africa. It is recognized as a variant of concern by WHO. This mutation was identified by the South African Genomics Monitoring Network. A cluster of SARS-CoV-2 viruses belonging to the B.1.1.529 lineage was detected and initial research showed that this form was highly contagious than the delta form, and that the current vaccines may not be able to provide sufficient protection against it. It is understood that as SARS-CoV-2 spreads, additional mutations may develop [12].

3.2. Malaria Epidemiology

Malaria is one of the most common diseases caused by Plasmodium parasites worldwide, that can be prevented and treated. Female Anopheles mosquitoes carry parasites that can be transmitted to humans through their bites [13]. When humans are infected with malaria, the parasites initially grow and multiply in the liver cells followed by red blood cells, where they multiply exponentially. The erythrocytic stage of the parasite's lifecycle causes malaria symptoms in humans [14]. High fever, sweats, chills, headache, and muscle pain are the most common symptoms of malaria. Symptoms often appear between seven and 18 days after a person is bitten by a mosquito carrying the virus [15]. Temperature, rainfall patterns, and relative humidity affect mosquito survival and malaria parasite growth. These environmental factors can affect the spread of malaria, as can public health services, use of pesticides, rate of drug resistance, and movement of people [16].

Following the successes of the Global Malaria Eradication Program in the 1950s and 1960s, malaria made a comeback in the 1970s due to drug and insecticide resistance as well as other operational restrictions. During this period, there was a significant change and change in malaria control activities, both of these contributed in malaria control [17]. Through renewed global community efforts and the introduction of the Roll Back Malaria Program in 1998, malaria has gained international attention, followed by emergence of many other anti-malarial initiatives. These new initiatives have increased funding for malaria control and the implementation of key interventions such as insecticide-treated nets, indoor residual spraying, and artemisinin-based combination therapy in many malaria-endemic countries [18]. However, there are numerous additional difficulties that require attention, including pesticide and medication resistance, new strains, concerns related to climate change, and the difficulties in universal access to therapies. The momentum gained must be maintained so that the final goal of malaria elimination or eradication can be achieved.

3.3. COVID-19 Vaccines

COVID-19 vaccines aim to protect health systems while reducing COVID-19 mortality and morbidity rates. To increase access to COVID-19 diagnostics, medicines, and vaccinations, WHO, the European Commission, and France devel-

oped COVAX as a worldwide risk-sharing structure for COVID-19 vaccine procurement and distribution. At least 78 high-income countries agreed to participate in the COVAX facility [19]. The COVAX is the most effective strategy for controlling the effects of pandemic on public health and economy [20]. A successful rollout of COVID-19 vaccines and prioritizing equal and universal access to the vaccine is the best response to the pandemic and its devastating consequences.

Since the beginning of the pandemic, individual precautions such as social distancing, wearing facemasks, practicing good hand hygiene, and limiting interpersonal interaction to outdoor settings have contributed to a reduction in the rate of virus transmission and mortality [21]. Governmental responses, such as school and workplace closures, public gathering bans, and travel bans, have helped too.

The effectiveness and safety of the vaccine, as well as its acceptance among the public and HCWs, appear to be critical in controlling the COVID-19 pandemic [22]. Several vaccinations have been developed, tested, and produced, and governments are turning to vaccinations as a panacea.

The WHO has approved several COVID-19 vaccines, such as those developed by Pfizer/BioNTech Community, Janssen/Ad26, COV 2.S (USA), AstraZeneca/AZD1222 (England), Sinopharm COVID-19, Sinovac-CoronaVac (China), SII/COVISHIELD, and Bharat Biotech BBV152 (India). The availability, safety, and effectiveness of vaccines are a major step in the fight against pandemics. Vaccines are monitored in real-time once they are widely distributed. As of April 30, 2022, more than 11 billion vaccine doses wadministered worldwide. However, income disparity has caused COVID-19 vaccine inequity. Low- and lower-middle-income countries have the least access to vaccination, making the risk of mutations even greater.

3.4. Malaria Vaccine

Malaria Plasmodium parasites were discovered by Alphonse Laveran in 1880, and there is a long history of innovation [23]. All attempts to develop vaccinations were unsuccessful before the approval of the world's first licensed malaria vaccine, RTS S, by European regulators in 2015 [24] [25]. In October 2021, WHO recommended the use of the RTS S/AS01 malaria vaccine for children in sub-Saharan Africa and other areas with moderate to high P. falciparum transmission [26]. It is recommended that the RTS S/AS01 malaria vaccine should be used extensively among children in sub-Saharan Africa and other regions with moderate to high P. falciparum malaria transmission rates. Currently, the malaria vaccine implementation program is carried out in Ghana, Kenya, and Malawi. It is anticipated that a total of 360,000 children will be vaccinated each year. Four doses of vaccination are administered to children aged 5 - 17 months, and they were found to drastically reduce the number of malaria cases, including deadly severe malaria, in young infants [27]. Most malaria interventions focus

on lowering the morbidity and mortality rates. The RTS S was tested for the prevention of pediatric clinical malaria.

3.5. Climate Elements' Effect on COVID-19 and Malaria

The effects of climate change on human health and disease are complex and multifaceted, and are intertwined with the effects of other natural and man-made health stressors [28]. Several studies have studied the links between climate and COVID-19 viruses [29]. Heat naturally destroys bacterial and viral particles [30]. In their study, Casanova *et al.* (2010) proved that most coronaviruses are still alive after two days at 20˚C and 80% relative humidity. At 40˚C, the virus inactivated faster than at 20˚C. Even with 50% relative humidity and a constant temperature, less than 1% of the viruses survived for two days in the laboratory [31]. It is proved that rising temperatures and increasing wind speeds decrease the rate at which the coronavirus accelerates and hence assists in slowing down the spread of the virus. This suggests that tropical countries should consider climatic factors while planning interventions [32]. Other studies show that relative humidity and temperature are negatively associated with coronavirus occurrence worldwide and that elevated temperature and humidity can partially suppress the virus [33]. The COVID-19 cases declined by 6.4 per day when the average daily temperature increased by 1˚C [34].

Scientists believe that diseases spread by mosquitoes benefit from rising temperatures as well as the other climatic changes [35]. The epidemic potential of malaria in tropical regions may increase due to climate change. Important elements that determine the spread of malaria are affected by shifts in climatic conditions, such as temperature and humidity, as well as rainfall and other types of precipitation. Temperature fluctuations influence the incubation period of malarial parasites and, thereby, the rate of malaria transmission. The temperature also influences the longevity, growth, and biting of mosquitoes, and has a significant impact on the phases of a mosquito's lifecycle [36]. Thus, rising temperatures are likely to increase the rate of malaria transmission [37]. An indirect correlation was observed between temperature and malaria. Further, international travel has the potential to reintroduce or accelerate malaria transmission in both tropical and temperate zones that have either eliminated or successfully managed malaria transmission [38].

4. Burden of COVID-19 Pandemic and Malaria

The COVID-19 pandemic is regarded as humanity's biggest health issue since World War II, with estimates that between 40% and 60% of the world's population will contract the virus [39]. As infections spread, most nations put restrictions on public movements through limited transportation, business and cultural activities, closed schools and colleges, canceled exams, and imposed social isolation.

Entertainment and tourism industries and hotel services were affected [40].

The pandemic affected children's and families' mental health. The global shutdown, from Asia to Europe to the United States of America, led to many of these challenges. Nonetheless, it had a significant socioeconomic impact on the financial markets with the situation described as "they are trembling, international financial markets are collapsing, all flights are canceled, and borders and transportation networks are closed" [41].

The burden of unpaid care increased during the pandemic. In return, organizations dedicated to alternative economic systems developed research and policy interventions to help society achieve environmental stability, economic sustainability, and social fairness in terms of income and employment, as well as unpaid care labor and volunteer community service [40].

Despite their vital role in the global health system, healthcare professionals are at a risk of infection due to direct patient contact. The ages of healthcare workers (HCWs) infected with COVID-19 ranged from 24 to 93 years, demonstrating that even young and healthy HCWs may be at risk. Asia appears to have lower infection rates among HCWs, possibly because of better preparedness for outbreaks or the lower health worker density in Southeast Asia [42].

The pandemic's effects are far-reaching, complex and are unlikely to disappear soon. For example, the pandemic may cost the United States of America between $16 trillion and $35 trillion by 2025. Long-term structural costs include education, diversity, wealth inequities, and the rise of late- and long-term health issues [43].

Lockdowns have recently been linked to air quality. Globally, significant environmental impacts were documented [44]. Air quality improved in 44 northern Chinese cities during the early stages of the lockdown and in different areas of India and Lima, Peru. A similar association was found between the number of COVID-19 cases and NO_2 concentration [45]. The lockout has resulted in a huge reduction in air pollution everywhere over the world, regardless of the geographical or meteorological conditions of the sites that are being taken into consideration [46]. Similarly, the air quality in Ecuador improved considerably during lockdowns, with a 23% decrease in NO_2 concentration [47]. Further, Berman (2020) found that the ongoing COVID-19 outbreak decreased particulate matter, namely PM2.5, emissions in the United States of America [48].

Malaria continues to be a serious public health concern worldwide. The WHO has published global malaria mortality figures since the turn of the century. Between 2000 and 2015, the worldwide annual mortality toll declined by over 40% from 896,000 to 562,000. Since then, the number of deaths has decreased. The African WHO region accounts for the greatest number of malaria cases and deaths. As a result, the consequences of even relatively slight disruptions to services to this at-risk population have nearly doubled the cases in sub-Saharan Africa since the turn of the century. The disease burden in turn has affected economic productivity. For example, the estimated "malaria penalty" to gross domestic product in Chad and Nigeria is 9% [49]. Median investment in the sub-Saharan African countries (2000-2004) would be one-third higher without

malaria and human immunodeficiency virus (HIV), around half of these is due to malaria [50].

The WHO African region accounted for 94% of the cases in 2019. The WHO Southeast Asian region accounts for approximately 3% of the world's malaria burden. The estimated numbers in the WHO Western Pacific region show that, there were 1.7 million cases in 2019, a 43% reduction from 3 million cases in 2000. A large decline in malaria cases has occurred in the WHO region of the Americas, from 1.5 million to 0.9 million. The incidence in this region decreased by 57% from 14 to 6 per 1000 population at-risk. Globally, around 40,900 malaria deaths were estimated to occur in 2019, with over 67% occurring in the under 5 age group. Malaria fatalities per 100,000 population at-risk declined from 25 in 2000 to 12 in 2015 and to 10 in 2019, with a slowdown in the latter year [51]. Malaria deaths impose heavy financial and manpower losses, and countries are condemned to stay in the cycle of ill health and poverty [52].

Due to global action, approximately 1.5 billion malaria cases and 7.6 million malaria deaths were averted between 2000 and 2019. Over two-thirds (62%) of the cases and 94% of the deaths averted were in the WHO African region. Over the past few years, significant interventions have reduced the incidence of malaria to a more manageable level. Bed nets treated with insecticides, indoor residual spraying, and artemisinin-based combination therapies have shown promise in lowering clinical disease and Plasmodium falciparum infection rates by 40% and 50%, respectively [35].

Consequently, the prevalence of malaria declined by 17% in 2019 compared to that in 2000, and the fatality rates caused by malaria declined by 16%. However, since 2014, the rate of reduction has slowed to the point where it has reversed in some areas of the African region [53]. In addition, approximately 29 countries account for 95% of the world's total malaria cases. Despite success in reducing the worldwide burden of malaria, malaria continues to be a significant global health problem in 2020. The number of expected deaths in 2020 was 627,000, a 12% increase over the number estimated in 2019. Of the additional 69,000 deaths, an estimated 47,004 (68%) were attributable to service disruptions caused by the COVID-19 pandemic [54].

Table 1 presents the percentage of total cases and deaths due to malaria in the WHO regions. The analysis showed that 88.9% of malaria cases and 93.84% of malaria deaths globally, during 2000-2020, were in the WHO African region, followed by the Southeast Asia region (7.69% of cases and 4.02% of deaths), the Eastern Mediterranean region (0.82% of cases and 0.59% of deaths) and Western Pacific region (0.38% of cases and 0.08% of deaths). During 2000–2020, the WHO European region did not record malaria deaths, and since 2015, the region is malaria-free.

Figure 1 shows a comparison between malaria burden in the African region and the rest of the malaria regions. The figure shows that the percentage of malaria in Africa over the past 20 years had a rate of infection ranging between 85.2% and 94.6% in 2005 and 2020, respectively. The highest share of cases and

Table 1. Proportion of total malaria cases and deaths across WHO regions from 2000 to 2020.

Region	Cases and deaths (%)		Cases and deaths averted (%)	
	Cases (%)	Deaths (%)	Cases (%)	Deaths (%)
Africa	88.90	93.84	82.2	95.2
Americas	7.69	4.02	1.0	0.1
South-East Asia	2.21	1.47	10	2.5
Europe	0.00	0.00	0.0	0.0
Eastern Mediterranean	0.82	0.59	4.9	1.6
Western Pacific	0.38	0.08	1.8	0.7

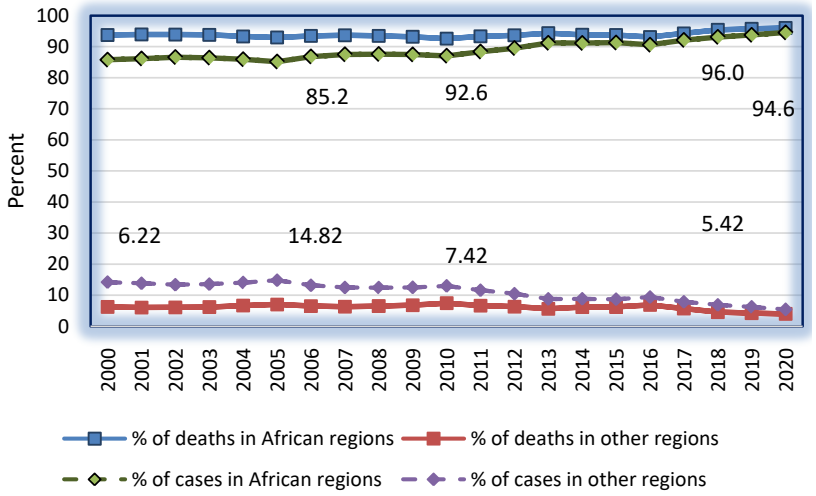

Figure 1. Proportion of deaths in WHO African region compared to other WHO regions. Source: WHO estimates.

deaths in the other regions combined was 14.82% in 2005 and 7.42% in 2010. The lowest percentage of cases and deaths was 5.42% in 2020 and 3.97% in 2020, respectively. Thus, Africa had the highest malaria burden, accounting for 95% of global cases and 96% of global deaths in 2019; around 80% of deaths occur in children under 5 years of age [54]. We can conclude that the number of deaths and cases of the disease has decreased significantly across all regions since 2000, and malaria has been eradicated from the WHO European region, whereas the WHO African region continues to bear the largest burden of malaria.

Table 2 presents descriptive statistics for the burden of malaria in Africa and other regions where malaria is endemic. In African region, the average percentage of cases was 88.97% (95% confidence interval (CI) of 87.7% - 90.2%) and a standard deviation (SD) of 2.9%. The mean percentage was 93.89% (95% CI 93.5 - 94.2, SD 0.86). As for the other regions combined, the average percentage of cases is equal to 11.03% (95% CI 9.79% - 12.27%, SD 2.9%, margin of error of 1.24%). The average percentage of deaths was 6.11% (95% CI 5.73% - 6.48%, SD 0.88, and a margin of error of 0.38).

Table 2. Burden of malaria in the African region compared to other WHO regions.

Statistics	African region		Other regions	
	% of deaths	% of cases	% of deaths	% of cases
count	21	21	21	21
Mean	93.89	88.97	6.11	11.03
standard deviation	0.86	2.90	0.88	2.90
sample variance	0.786	8.42	0.78	8.42
confidence interval 95% (lower)	93.52	87.73	5.73	9.79
confidence interval 95% (upper)	94.27	90.21	6.48	12.27
margin of error	0.38	1.24	0.38	1.24

After 2005, there was a significant reduction in the population infected with malaria, and it was one of the largest declines in infection prevalence since 1900. This reduction was brought about by the financial response of the Global Fund, as well as the technical revisions to policy made by the WHO [55]. However, our analysis of the number of cases and deaths from malaria shows that the burden of malaria was higher in Africa than in other regions and that Africa alone faced this burden (**Figure 1**). The number of deaths and cases were stable for more than 20 years and is much higher than in any other place where malaria is endemic.

Thus, the African region continues to bear a disproportionately high percentage of the global malaria burden. In 2020, the region was responsible for 96% of all deaths and 95% of all malaria cases (**Figure 2**). Approximately 80% of all malaria deaths in the region occurred in children under five years of age [54]. The history of malaria in the African region is complicated. There were ideal lulls when pharmaceuticals worked, and droughts prevented mosquitoes from transmitting infection; there were worse scenarios due to drugs resistance and flooding that affected wide regions of Africa.

5. Challenges of Malaria and COVID-19

The transmission of COVID-19 in Africa is believed to be less widespread than anticipated. As of April 29, 2022, there were 510,270,667 confirmed COVID-19 cases and 6,233,667 deaths reported worldwide by the WHO [7]. Notably, the confirmed numbers of cases and deaths in Africa were only 8,813,883 (1.73%) and 171,638 (2.75%), respectively. Demography and the age structure of a population may contribute to this disparity in mortality rates between regions. Although a COVID-19 outbreak did not emerge in malaria-endemic regions, the WHO has encouraged health ministries and national malaria control programs to ensure that malaria control actions are not hampered [56]. As the COVID-19 pandemic grows, it is important to tackle the novel coronavirus while not overlooking other fatal diseases, such as malaria. African countries must be ready for difficulties caused by COVID-19, while continuing to address the challenges caused by HIV/AIDS.

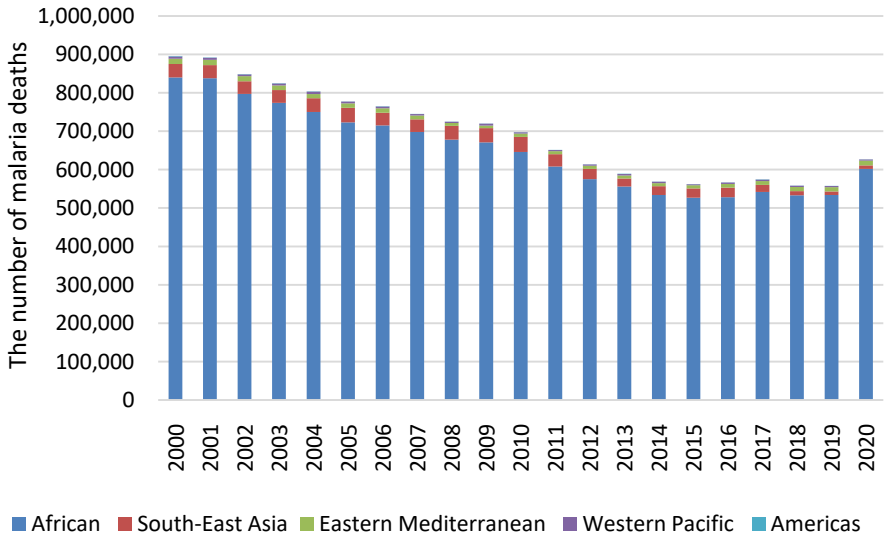

Figure 2. Global malaria death estimates across WHO regions between 2000-2020. Source: WHO estimates.

Due to globalization, people, ideas, money, goods, data, medications, weapons, and many other things are transported worldwide every day. Transmission of diseases is an additional concern included in this list. Hence, it is important to increase efforts to create effective vaccines for malaria and COVID-19 and make them available to everyone, as this is the most effective preventive approach for disease control, at global level.

Malaria mainly affects poor, tropical, and subtropical regions, with cases predominantly in children. Due to the high malaria fatality rates in Africa, much of the research has focused on this disease [56]. Malaria is the leading cause of child mortality and second leading cause of mortality in adolescents worldwide [24]. Globally, it accounts for 7.4% of all adolescent deaths reported to the WHO each year (Mbacham *et al.* 2019) and a leading cause of death in the 10 - 14 year age group, accounting for 14.1% of all cause fatalities; in this age group. The burden is higher and focusing on malaria is significantly more important than focusing on tuberculosis or HIV/AIDS [57].

There were great efforts by WHO, governments, and civil society organizations to combat malaria in the past 20 years. However, in 2020, all the progress against malaria has declined. Due to the COVID-19 pandemic, the number of malaria cases increased for the first time in the past 20 years, an increase likely related to the interruption of health services during the pandemic.

Figure 3 and **Figure 4** represent the number of COVID-19 cases and deaths in malaria-endemic regions, according to the WHO regions (as of 29 April 2022). These figures show that the Americas was the region most affected by COVID-19. The figures show that the highest number of cases occurred in Europe, that is due to the Omicron variant [58], followed by the Americas. The highest number of deaths occurred in the Americas followed by Europe. The burden is lighter in Southeast Asia, the Eastern Mediterranean, the Western Pacific,

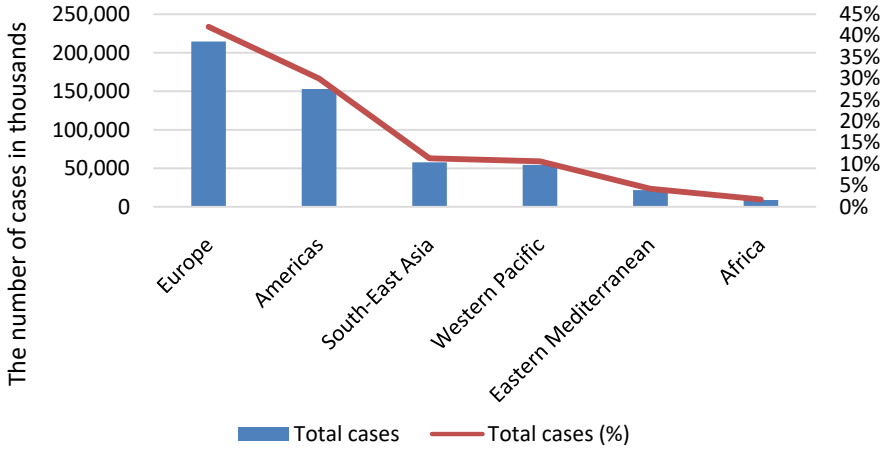

Figure 3. Distribution of COVID-19 cases across WHO regions as of April 29, 2022.

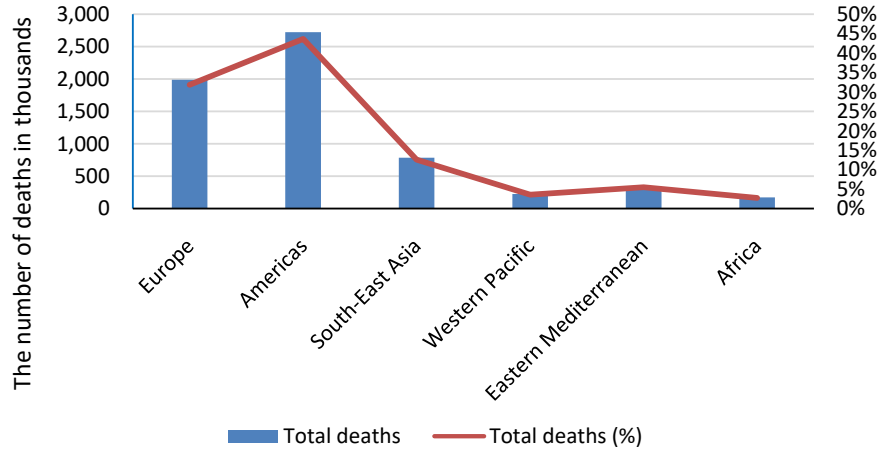

Figure 4. Distribution of COVID-19 deaths across WHO regions as of April 29, 2022.

and Africa. This finding supports the idea that there was a decline in the number of deaths caused by COVID-19 in areas where malaria is endemic. The Americas were the most affected by COVID-19. Both the United States of America and Brazil have an unusually high number of deaths and cases of coronavirus. The pandemic had a catastrophic impact on Latin America, and numerous countries have documented a rebound in COVID-19 cases. However, countries such as Argentina, Chile, and Panama have begun vaccination campaigns for large groups of people [59].

6. Conclusions

The concern over communicable illnesses dates back throughout history; to epidemics and pandemics that caused numerous deaths. Vector control is still widely considered a cornerstone of malaria control. Recently, high-income countries have eradicated and eliminated malaria by employing aggressive prevention and control measures as well as using more effective monitoring and evaluation strategies. In one-third of malaria-endemic countries, malaria prevalence declined by at least 50% in the previous decade. Current malaria control measures

are ineffective in eradicating the disease entirely, and as a result, most countries have abandoned the goal of eradication. Therefore, malaria vaccines are seen by many as a crucial strategy for controlling malaria. Globally, public health experts have engaged in a constant struggle to find a malaria vaccine that is safe, affordable, and effective. This fight has eventually led to impressive developments, such as the discovery of the RTS S/AS01 malaria vaccine.

It is well known that epidemics and economic crises disproportionately affect vulnerable populations, thereby increasing inequality and poverty. Global crises require cooperation, solidarity, and sound socioeconomic and public health strategies. For a very long time, a community plagued by malaria was also a poor community [52]. Malaria is common in the tropical and subtropical parts of the world, and remains a major public health problem in many poor countries, especially in Africa, and some parts of Asia.

The COVID-19 pandemic has impacted populations worldwide, and the challenges span several areas of expertise, making it difficult to find effective solutions. Vaccine hesitation remains a concern as variants arise and spread worldwide, reducing the certainty of herd immunity. Ongoing management and a reduction of losses caused by this pandemic is the primary priority.

The spillover effects of the COVID-19 pandemic have increased the malaria burden in Africa, where malaria threatens the lives of millions of people. The increased burden of the disease is also likely to be associated with HIV and tuberculosis as public health programs for these are affected due to the pandemic. Therefore, public health measures to combat malaria also need to ensure reduction of disruptions in healthcare that affect ongoing control measures. Future research comparing COVID-19 to other diseases may assist in understanding its systemic and regional consequences.

The findings of this study have to be seen considering some limitations. We estimated the burden of malaria using the number of death and the number of cases. At a global level, it is likely that countries may have different regulations for registering COVID-19 death. In contrast, in countries where only laboratory-confirmed cases are counted, the overall number of coronavirus-related fatalities would be higher. For instance, in Belgium, all non-hospitalized patients presenting symptoms of COVID-19 are included in the official reports on coronavirus-related mortality. As a result, the overall number of reported death appears to be higher. This study has a potential flaw due to the use of open-source data, which has prompted this research to be restructured. Nonetheless, this does not undermine the validity or trustworthiness of the overall finding.

Ethics Approval

Because the data used in this study were obtained from publicly available sources, institutional review board approval was not required for its completion.

Availability of Data and Materials

The datasets for the current study are available from the corresponding author

upon reasonable request.

Authors' Contributions

Hamid H. Hussien carried out data analysis and drafted the manuscript, as well as interpretation of the findings and revision of the manuscript. Hamid H. Hussien has read the final draft of the manuscript.

Conflicts of Interest

There is no conflict of interest for this work.

References

[1] Chen, X.G., Li, H., Lucero-Prisno, D.E., *et al.* (2020) What Is Global Health? Key Concepts and Clarification of Misperceptions: Report of the 2019 GHRP Editorial Meeting. *Global Health Research and Policy*, **5**, Article No. 14. https://doi.org/10.1186/s41256-020-00142-7

[2] Chanda-Kapata, P., Kapata, N. and Zumla, A. (2020) COVID-19 and Malaria: A Symptom Screening Challenge for Malaria Endemic Countries. *International Journal of Infectious Diseases*, **94**, 151-153. https://doi.org/10.1016/j.ijid.2020.04.007

[3] Di Gennaro, F., Marotta, C., Locantore, P., Pizzol, D. and Putoto, G. (2020) Malaria and COVID-19: Common and Different Findings. *Tropical Medicine and Infectious Disease*, **5**, Article No. 141. https://doi.org/10.3390/tropicalmed5030141

[4] Ortiz-Prado, E., Simbaña-Rivera, K., Gómez-Barreno, L., *et al.* (2020) Clinical, Molecular, and Epidemiological Characterization of the SARS-CoV-2 Virus and the Coronavirus Disease 2019 (COVID-19), a Comprehensive Literature Review. *Diagnostic Microbiology and Infectious Disease*, **98**, Article ID: 115094. https://doi.org/10.1016/j.diagmicrobio.2020.115094

[5] Han, E., Tan, M.M.J., Turk, E., *et al.* (2020) Lessons Learnt from Easing COVID-19 Restrictions: An Analysis of Countries and Regions in Asia Pacific and Europe. *The Lancet*, **396**, 1525-1534. https://doi.org/10.1016/S0140-6736(20)32007-9

[6] Rothan, H.A. and Byrareddy, S.N. (2020) The Epidemiology and Pathogenesis of Coronavirus Disease (COVID-19) Outbreak. *Journal of Autoimmunity*, **109**, Article ID: 102433. https://doi.org/10.1016/j.jaut.2020.102433

[7] Center on Budget and Policy Priorities (2021) Tracking the COVID-19 Recession's Effects on Food, Housing, and Employment Hardships. Center on Budget and Policy Priorities, Washington DC. http://www.jstor.org/stable/resrep28464

[8] World Health Organization (2020) Coronavirus Disease 2019 (COVID-19) Situation Report-73. WHO, Geneva. https://apps.who.int/iris/bitstream/handle/10665/331686/nCoVsitrep02Apr2020-eng.pdf?sequence=1&isAllowed=y

[9] Ahmad, A.R. and Murad, H.R. (2020) The Impact of Social Media on Panic during the COVID-19 Pandemic in Iraqi Kurdistan: Online Questionnaire Study. *Journal of Medical Internet Research*, **22**, e19556. https://doi.org/10.2196/19556

[10] Keulertz, M., Mulligan, M. and Allan, J.A. (2020) The Impact of COVID-19 on Water and Food Systems: Flattening the Much Bigger Curve Ahead. *Water International*, **45**, 430-434. https://doi.org/10.1080/02508060.2020.1779515

[11] Christie, A., Brooks, J.T., Hicks, L.A., *et al.* (2021) Guidance for Implementing COVID-19 Prevention Strategies in the Context of Varying Community Transmis-

sion Levels and Vaccination Coverage. *MMWR. Morbidity and Mortality Weekly Report*, **70**, 1044-1047. https://doi.org/10.15585/mmwr.mm7030e2

[12] World Health Organization (2021) Classification of Omicron (B.1.1.529): SARS-CoV-2 Variant of Concern. https://www.who.int/news/item/26-11-2021-classification-of-omicron-(b.1.1.529)-sars-cov-2-variant-of-concern#:~:text=known%20confirmed%20B.-,1.1.,as%20compared%20to%20other%20VOCs

[13] Vythilingam, I., NoorAzian, Y.M., Huat, T., *et al.* (2008) Plasmodium Knowlesi in Humans, Macaques and Mosquitoes in Peninsular Malaysia. *Parasites & Vectors*, **1**, Article No. 26. https://doi.org/10.1186/1756-3305-1-26

[14] Keasling, J.D., Diagana, T.T., Hale, V. and Renninger, N. (2007) Microbially Derived Artemisinin: A Biotechnology Solution to the Global Problem of Access to Affordable Antimalarial Drugs. *The American Journal of Tropical Medicine and Hygiene*, **77**, 198-202. https://doi.org/10.4269/ajtmh.2007.77.198

[15] Behrens, R.H., Neave, P.E. and Jones, C.O.H. (2015) Imported Malaria among People Who Travel to Visit Friends and Relatives: Is Current UK Policy Effective or Does It Need a Strategic Change? *Malaria Journal*, **14**, Article No. 149. https://doi.org/10.1186/s12936-015-0666-7

[16] Hoshen, M.B. and Morse, A.P. (2004) [No Title Found]. *Malaria Journal*, **3**, Article No. 32. https://doi.org/10.1186/1475-2875-3-32

[17] Nájera, J.A., González-Silva, M. and Alonso, P.L. (2011) Some Lessons for the Future from the Global Malaria Eradication Programme (1955-1969). *PLoS Medicine*, **8**, e1000412. https://doi.org/10.1371/journal.pmed.1000412

[18] Chuang, I. and Richie, T.L. (2012) World Malaria Report 2010: Documenting Progress towards Malaria Eradication. *Expert Review of Vaccines*, **11**, 39-41. https://doi.org/10.1586/erv.11.165

[19] Finch, W.H. and Hernández Finch, M.E. (2020) Poverty and Covid-19: Rates of Incidence and Deaths in the United States during the First 10 Weeks of the Pandemic. *Frontiers in Sociology*, **5**, Article No. 47. https://doi.org/10.3389/fsoc.2020.00047

[20] Wouters, O.J., Shadlen, K.C., Salcher-Konrad, M., *et al.* (2021) Challenges in Ensuring Global Access to COVID-19 Vaccines: Production, Affordability, Allocation, and Deployment. *The Lancet*, **397**, 1023-1034. https://doi.org/10.1016/S0140-6736(21)00306-8

[21] Liao, M.R., Liu, H.Y., Wang, X., *et al.* (2021) A Technical Review of Face Mask Wearing in Preventing Respiratory COVID-19 Transmission. *Current Opinion in Colloid & Interface Science*, **52**, Article ID: 101417. https://doi.org/10.1016/j.cocis.2021.101417

[22] Kuter, B.J., Browne, S., Momplaisir, F.M., *et al.* (2021) Perspectives on the Receipt of a COVID-19 Vaccine: A Survey of Employees in Two Large Hospitals in Philadelphia. *Vaccine*, **39**, 1693-1700. https://doi.org/10.1016/j.vaccine.2021.02.029

[23] Cox, F.E.G. (2020) History of the Discovery of the Malaria Parasites and Their Vectors. *Parasites & Vectors*, **3**, Article No. 5. https://doi.org/10.1186/1756-3305-3-5

[24] Walther, M. (2006) Advances in Vaccine Development against the Pre-Erythrocytic Stage of Plasmodium Falciparum Malaria. *Expert Review of Vaccines*, **5**, 81-93. https://doi.org/10.1586/14760584.5.1.81

[25] Schellenberg, D. (2018) An Evaluation of the Cluster-Randomized Pilot Implementation of RTS,S/AS01 through Routine Health Systems in Moderate to High Malaria Transmission Settings in Africa. The Malaria Vaccine Pilot Evaluation. World Health Organization, Geneva.

[26] Casares, S., Brumeanu, T.-D. and Richie, T.L. (2010) The RTS,S Malaria Vaccine. *Vaccine*, **28**, 4880-4894. https://doi.org/10.1016/j.vaccine.2010.05.033

[27] Chandramohan, D., Zongo, I., Sagara, I., *et al.* (2021) Seasonal Malaria Vaccination with or without Seasonal Malaria Chemoprevention. *New England Journal of Medicine*, **385**, 1005-1017. https://doi.org/10.1056/NEJMoa2026330

[28] Gamble, J., Balbus, J., Berger, M., *et al.* (2016) The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Report. Other Government Series. Geology, Minerals, Energy, and Geophysics Science Center, Reston. https://pubs.er.usgs.gov/publication/70193757 https://doi.org/10.7930/J0Q81B0T

[29] Mecenas, P., da Rosa Moreira Bastos, R.T., Vallinoto, A.C.R. and Normando, D. (2020) Effects of Temperature and Humidity on the Spread of COVID-19: A Systematic Review. *PLOS ONE*, **15**, e0238339. https://doi.org/10.1371/journal.pone.0238339

[30] Biryukov, J., Boydston, J.A., Dunning, R.A., *et al.* (2021) SARS-CoV-2 Is Rapidly Inactivated at High Temperature. *Environmental Chemistry Letters*, **19**, 1773-1777. https://doi.org/10.1007/s10311-021-01187-x

[31] Casanova, L.M., Jeon, S., Rutala, W.A., *et al.* (2010) Effects of Air Temperature and Relative Humidity on Coronavirus Survival on Surfaces. *Applied and Environmental Microbiology*, **76**, 2712-2717. https://doi.org/10.1128/AEM.02291-09

[32] Rosario, D.K.A., Mutz, Y.S., Bernardes, P.C. and Conte-Junior, C.A. (2020) Relationship between COVID-19 and Weather: Case Study in a Tropical Country. *International Journal of Hygiene and Environmental Health*, **229**, Article ID: 113587. https://doi.org/10.1016/j.ijheh.2020.113587

[33] Wu, Y., Jing, W.Z., Liu, J., *et al.* (2020) Effects of Temperature and Humidity on the Daily New Cases and New Deaths of COVID-19 in 166 Countries. *Science of the Total Environment*, **729**, Article ID: 139051. https://doi.org/10.1016/j.scitotenv.2020.139051

[34] Heibati, B., Wang, W.G., Ryti, N.R.I., *et al.* (2021) Weather Conditions and COVID-19 Incidence in a Cold Climate: A Time-Series Study in Finland. *Frontiers in Public Health*, **8**, Article ID: 605128. https://doi.org/10.3389/fpubh.2020.605128

[35] Parham, P.E. and Michael, E. (2010) Modeling the Effects of Weather and Climate Change on Malaria Transmission. *Environmental Health Perspectives*, **118**, 620-626. https://doi.org/10.1289/ehp.0901256

[36] Mouchet, J., Manguin, S., Sircoulon, J., *et al.* (1998) Evolution of Malaria in Africa for the Past 40 Years: Impact of Climatic and Human Factors. *Journal of the American Mosquito Control Association*, **14**, 121-130.

[37] Afrane, Y.A., Little, T.J., Lawson, B.W., Githeko, A.K. and Yan, G.Y. (2008) Deforestation and Vectorial Capacity of Anopheles Gambiae Giles Mosquitoes in Malaria Transmission, Kenya. *Emerging Infectious Diseases*, **14**, 1533-1538. https://doi.org/10.3201/eid1410.070781

[38] Wickremasinghe, R., Wickremasinghe, A.R. and Fernando, S.D. (2012) Climate Change and Malaria a Complex Relationship. *UN Chronicle*, **47**, 21-25. https://doi.org/10.18356/2374a00e-en

[39] Tovar, J. (2021) Soccer, World War II and Coronavirus: A Comparative Analysis of How the Sport Shut Down. *Soccer & Society*, **22**, 66-74. https://doi.org/10.1080/14660970.2020.1755270

[40] Sigala, M. (2020) Tourism and COVID-19: Impacts and Implications for Advancing and Resetting Industry and Research. *Journal of Business Research*, **117**, 312-321.

https://www.sciencedirect.com/science/article/pii/S0148296320303908
https://doi.org/10.1016/j.jbusres.2020.06.015

[41] Dube, K., Nhamo, G. and Chikodzi, D. (2021) COVID-19 Pandemic and Prospects for Recovery of the Global Aviation Industry. *Journal of Air Transport Management*, **92**, Article ID: 102022. https://doi.org/10.1016/j.jairtraman.2021.102022

[42] Power, K. (2020) The COVID-19 Pandemic Has Increased the Care Burden of Women and Families. *Sustainability*: *Science*, *Practice and Policy*, **16**, 67-73. https://doi.org/10.1080/15487733.2020.1776561

[43] Yeyati, E.L. and Filippini, F. (2021) Social and Economic Impact of COVID-19. Department of Economics Working Papers wp_gob_2021_09, Universidad Torcuato Di Tella.

[44] Bashir, M.F., Ma, B.J. and Shahzad, L. (2020) A Brief Review of Socio-Economic and Environmental Impact of Covid-19. *Air Quality*, *Atmosphere & Health*, **13**, 1403-1409. https://doi.org/10.1007/s11869-020-00894-8

[45] Bao, R. and Zhang, A. (2020) Does Lockdown Reduce Air Pollution? Evidence from 44 Cities in Northern China. *Science of the Total Environment*, **731**, Article ID: 139052. https://doi.org/10.1016/j.scitotenv.2020.139052

[46] Kumari, P. and Toshniwal, D. (2020) Impact of Lockdown on Air Quality over Major Cities across the Globe during COVID-19 Pandemic. *Urban Climate*, **34**, Article ID: 100719. https://doi.org/10.1016/j.uclim.2020.100719

[47] Zalakeviciute, R., Vasquez, R., Bayas, D., *et al.* (2020) Drastic Improvements in Air Quality in Ecuador during the COVID-19 Outbreak. *Aerosol and Air Quality Research*, **20**, 1783-1792. https://doi.org/10.4209/aaqr.2020.05.0254

[48] Berman, J.D. and Ebisu, K. (2020) Changes in U.S. Air Pollution during the COVID-19 Pandemic. *Science of the Total Environment*, **739**, Article ID: 139864. https://doi.org/10.1016/j.scitotenv.2020.139864

[49] Okorosobo, T., Okorosobo, F., Mwabu, G., Orem, J.N. and Muthuri Kirigia, J. (2011) Economic Burden of Malaria in Six Countries of Africa. *European Journal of Business and Management*, **3**, 42-63.

[50] Azemar, C. and Desbordes, R. (2009) Public Governance, Health and Foreign Direct Investment in Sub-Saharan Africa. *Journal of African Economies*, **18**, 667-709. https://doi.org/10.1093/jae/ejn028

[51] World Health Organization (2020) World Malaria Report 2020: 20 Years of Global Progress and Challenges. WHO, Geneva. https://doi.org/10.30875/60123dd4-en

[52] World Health Organization (2020) Tailoring Malaria Interventions in the COVID-19 Response.
https://www.who.int/malaria/publications/atoz/tailoring-malaria-interventions-covid-19.pdf?ua=1

[53] Mbacham, W.F., Ayong, L., Guewo-Fokeng, M. and Makoge, V. (2019) Malaria Control and Elimination. Vol. 2013. MIMB 1064-3745. Humana, New York.

[54] World Health Organization (2022) World Malaria Report 2021.
https://www.who.int/publications/i/item/9789240040496

[55] Hanefeld, J. (2014) The Global Fund to Fight AIDS, Tuberculosis and Malaria: 10 Years on. *Clinical Medicine*, **14**, 54-57.
https://doi.org/10.7861/clinmedicine.14-1-54

[56] Hogan, A.B., Jewell, B.L., Sherrard-Smith, E., *et al.* (2020) Potential Impact of the COVID-19 Pandemic on HIV, Tuberculosis, and Malaria in Low-Income and Middle-Income Countries: A Modelling Study. *The Lancet Global Health*, **8**, e1132-e1141.

https://doi.org/10.1016/S2214-109X(20)30288-6

[57] Lalloo, D.G., Olukoya, P. and Olliaro, P. (2006) Malaria in Adolescence: Burden of Disease, Consequences, and Opportunities for Intervention. *The Lancet Infectious Diseases*, **6**, 780-793. https://doi.org/10.1016/S1473-3099(06)70655-7

[58] Bazant, M.Z. and Bush, J.W.M. (2021) A Guideline to Limit Indoor Airborne Transmission of COVID-19. *Proceedings of the National Academy of Sciences*, **118**, e2018995118. https://doi.org/10.1073/pnas.2018995118

[59] Rodriguez-Morales, A.J. and Franco, O.H. (2021) Public Trust, Misinformation and COVID-19 Vaccination Willingness in Latin America and the Caribbean: Today's Key Challenges. *The Lancet Regional Health—Americas*, **3**, Article ID: 100073. https://doi.org/10.1016/j.lana.2021.100073