Journal of Travel Medicine
International Society of Travel Medicine
Promoting healthy travel worldwide
Established 1991
Journal of Travel Medicine, 2021, 1–12
https://doi.org/10.1093/jtm/taab046
Advance Access Publication Date: 24 March 2021
Original Article

Original Article

Trends of the global, regional and national incidence of malaria in 204 countries from 1990 to 2019 and implications for malaria prevention

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Submitted 3 March 2021; Revised 0 Month 0000; Editorial Decision 18 March 2021; Accepted 22 March 2021

Abstract

Background: Malaria is a life-threatening disease worldwide, but lacks studies on its incidence at the global level. We aimed to describe global trends and regional diversities in incidence of malaria infection, to make global tailored implications for malaria prevention.

Methods: We used the data from the Global Burden of Disease Study 2019. The age-standardized incidence rate (ASR) and absolute number of malaria episodes showed the epidemic status of malaria infection. The estimated annual percentage change of ASR and changes in malaria episodes quantified the malaria incidence trends. The connection between ASRs and traveller number indicated infection risk for travellers.

Results: Globally, the malaria ASR decreased by an average 0.80% (95% confidence interval 0.58–1.02%) per year from 1990 to 2019; however, it slightly increased from 3195.32 per 100 000 in 2015 to 3247.02 per 100 000 in 2019. The incidence rate of children under 5 was higher than other age groups. A total of 40 countries had higher ASRs in 2019 than in 2015, with the largest expansion in Cabo Verde (from 2.02 per 100 000 to 597.00 per 100 000). After 2015, the ASRs in high-middle, middle and low-middle Socio-demographic Index regions began to rise and the uptrends remained in 2019. Central, Western and Eastern Sub-Saharan Africa had the highest ASRs since 1990, and traveller number in Eastern and Western Sub-Saharan Africa increased by 31.24 and 7.58%, respectively, from 2017 to 2018. Especially, most countries with ASR over 10 000 per 100 000 had increase in traveller number from 2017 to 2018, with the highest change by 89.56% in Mozambique.

Conclusions: Malaria is still a public health threat for locals and travellers in Sub-Saharan Africa and other malaria-endemic areas, especially for children under 5. There were unexpected global uptrends of malaria ASRs from 2015 to 2019. More studies are needed to achieve the goal of malaria elimination.

Key words: Malaria, incidence, trend, prevention

Introduction

Malaria is considered a major public health problem with high morbidity and mortality. Despite being preventable and curable, malaria continues to have a devastating impact on people's health and livelihoods around the world. Almost half the world's population, living in nearly 100 countries and territories, are at risk of malaria.[1] In 2018, World Health Organization (WHO) reported that an estimated 228 million malaria episodes occurred worldwide; most of them were in the WHO Africa Region (93%).[2] WHO also reported an estimated 405 000 deaths from malaria in 2018 globally, with children under 5 years accounting for 67% of all malaria deaths worldwide.[2]

Research showed that in malaria-endemic countries, severe malaria, infection associated with end organ damage, was more common in children under 5 years old compared with older children and adults, which affects local children's growth a lot.[3]

In addition to the health burden on individuals and populations, malaria has negative consequences for national economies, for a 10% reduction in malaria case incidence was observed an association with a nearly 0.3% increase in the level of per capita income globally over the period 2000–17, underscoring the importance of malaria control in the agenda for sustainable development.[1,4]

Previous study had found a rapid decline in malaria burden between 2005 and 2017, with incidence declining by 27.9%.[5] However, the decreasing of malaria incidence in some parts of the world does not diminish the serious risk that each individual takes by visiting a currently endemic area, for travellers from non-endemic areas do not have acquired immunity against malaria.[6] It was estimated that over 125 million travellers visiting endemic countries were facing the risk of malaria infection every year.[7]

The vision of WHO and the global malaria community is a world free of malaria.[8] As part of this vision, the Global Technical Strategy for Malaria 2016–2030 (GTS) sets ambitious yet feasible global targets for 2030 with milestones for measuring progress for 2020 and 2025, which is reducing malaria mortality rates and malaria case incidence globally by at least 40% by 2020, 75% by 2025 and 90% by 2030, compared with 2015.[8] However, WHO reported that progress has stalled or trends are in the wrong direction for global malaria incidence.[9] Despite 31 countries reduced case incidence significantly between 2015 and 2018 and were on track to reduce incidence by 40% or more by 2020, the world is not on track to meet the 2020 milestones that will lead us to lower case incidence and mortality by 90% by 2030 (from 2015 levels).[2]

Recent studies had shown huge progress in reducing malaria episodes and deaths between 2000 and 2017, which, however, lacked description of malaria infection in different age groups and could not explain the stalling of global progress in the last 5 years.[5,10] Therefore, we need updated information about malaria infection to better understand the global incidence trends of malaria infection. In this present study, we analysed the current epidemic status of malaria infection and malaria incidence trends from 1990 to 2019 at global, regional and national levels, using the data on the incidence of malaria infection from Global Burden of Disease Study 2019 (GBD 2019) results.[11] Our study can serve as an extension and complement to previous studies and describes the global landscape, long-term trends and regional differences in incidence of malaria infection, while also giving comprehensive perspective for global to achieve the goals of malaria elimination.

Methods

Data source

The GBD study is co-ordinated by the Institute for Health Metrics and Evaluation at the University of Washington, USA[12] and consists of a systematic and scientific effort to quantify the comparative magnitude of health losses due to diseases by sex, age and location over time.[13] We used the data obtained in the GBD 2019, which covered 204 countries and territories between 1990 and 2019.[14] From the website Global Health Data Exchange, established by GBD group, we extracted annual episodes and incidence rates of malaria from 1990 to 2019, by sex, age, region and country.[15] The general methodological approaches to estimate the incidence of malaria infection were described elsewhere.[14] To make the estimated value as close as possible to the real value, separate modelling strategies were developed for countries inside Sub-Saharan Africa vs those outside, except 16 African countries with epidemiological and data availability/quality more akin to non-Africa settings.[14] Briefly, routine malaria case reports from national routine surveillance systems were reviewed to estimate the infection prevalence for *Plasmodium falciparum* (referred to hereafter as *P. falciparum* parasite rate, *Pf*PR) in countries outside Sub-Saharan Africa; cross-sectional, geolocated and community-representative observations of *Pf*PR were reviewed to estimate the incidence of malaria infection in countries inside Sub-Saharan Africa by a series of models.[14] The number of episodes due to *Plasmodium vivax* was calculated by applying the fraction of *P. vivax* and *P. falciparum* obtained from WHO and a literature review, inside the Sub-Saharan Africa; outside Sub-Saharan Africa, the identical procedure for *P. vivax* and *P. falciparum* was followed.[14] The number of total malaria episodes were then estimated. These modelled data from GBD study made it possible to compare malaria incidence in different countries.

We reported the incidence of malaria infection in 204 countries and territories, which were classified into five regions by the Socio-demographic Index (SDI). The SDI is developed by GBD researchers and is a composite indicator of total fertility rate under age 25 years, years of education for those aged 15 and older, and lag distributed income per capita.[16] The 204 countries and territories were also divided into 21 regions (Central Asia, Western Europe, Central Sub-Saharan Africa, etc.) based on their epidemiological homogeneity and geographical contiguity. In this study, age groups included under 5, 5–14, 15–49, 50–69 and 70 plus years.

In addition, to better understand and establish visualization for the risk levels of malaria infection for travellers in different regions, we extracted the number of travellers arriving certain countries in 2017 and 2018 from websites of United Nations and The World Bank.[17,18]

Statistical analysis

The epidemic status of malaria infection was shown by the age-standardized incidence rate (ASR) and absolute number of malaria episodes. The estimated annual percentage change (EAPC) of ASR as well as changes in malaria episodes quantified the malaria incidence trends. The association between the change of traveller number and ASRs indicated the risk level of malaria infection in different areas.

ASRs were calculated by applying the age-specific rates for each location, sex and year to a GBD World Standard Population, in order to compare populations with different age structures or for the same population over time in which the age profiles change accordingly.[19] Absolute number of malaria episodes represented the actual condition of malaria infection in each country or region.

Relative changes in malaria episodes were defined as $\frac{\text{Episodes}_{2019}-\text{Episodes}_{1990}}{\text{Episodes}_{1990}} \times 100\%$. EAPC is a summary and widely used to measure the ASR trend over a specified interval. A regression line was fitted to the natural logarithm of the rates, i.e. $y = \alpha + \beta x + \varepsilon$, where $y = \ln$ (ASR) and x = calendar year. In particular, when the number of ASR was 0, we replaced it with 0.01. The EAPC was calculated as $100 \times (e^{\beta} - 1)$, with 95% confidence intervals (CIs) obtained from the linear regression model. In describing trends, the term 'increase' was used when the EAPC estimation and the lower boundary of its 95% CI were both >0. In contrast, the term 'decrease' was used when the EAPC estimation and the upper boundary of its 95% CI were both <0. Otherwise, the term 'stable' was used.

Changes of traveller number were calculated by $\frac{\text{Travellers}_{2018} - \text{Travellers}_{2017}}{\text{Travellers}_{2017}} \times 100\%$. We further analysed the association between ASRs and the change of traveller number to find out countries or regions which need more attention on malaria prevention for travellers.

Results

Global and national trends in incidence of malaria infection

Globally, the ASR of malaria infection decreased by an average 0.80% (95% CI 0.58–1.02%) per year from 4084.08 per 100 000 in 1990 to 3247.02 per 100 000 in 2019 (Table 1). The ASR of malaria decreased stagnated with minor fluctuation, from 4084.08 per 100 000 in 1990 to 3877.86 per 100 000 in 2010. A significant decline in malaria ASR was observed from 3877.86 per 100 000 in 2010 to 3195.32 per 100 000 in 2015; however, a slight increase was subsequently observed from 3195.32 per 100 000 in 2015 to 3247.02 per 100 000 in 2019 (Supplementary Figure S1). Gender disparity was low in global malaria ASRs. The incidence rate of children under the age of 5 was much higher than people in other age groups (Supplementary Figure S2).

Malaria ASR distributed heterogeneously in different countries (Figure 1A). There were 116 countries and territories, which reported zero malaria episodes in 2019 (China, Maldives, Sri Lanka, etc.). However, 13 countries and territories reported ASRs over 20 000 per 100 000, with the highest in Benin (27 623.45 per 100 000). Geographically, these places are gathered in Western Sub-Saharan Africa (Benin, Liberia, Cote d'Ivoire, Sierra Leone, Togo, Nigeria, Guinea), Central Sub-Saharan Africa (Central African Republic, Democratic Republic of the Congo, Gabon, Equatorial Guinea, Congo) and Eastern Sub-Saharan Africa (Mozambique). These countries had high malaria ASR and accounted for more than half (52.77%) of the total global malaria episodes in 2019 (122.03 million in 231.36 million), with the highest proportion in Nigeria (25.13%), followed by Congo (11.97%) and Uganda (4.63%).

From 1990 to 2019, malaria ASR all over the world decreased at different paces with the largest decrease in Tajikistan (EAPC = −43.09; 95% CI −48.78–36.77) and the smallest in Niger (EAPC = −0.72; 95% CI −1.22–0.21) (Figure 1C). However, the number of malaria episodes increased in 29 countries, with the largest growth in Cabo Verde, from four in 1990 to 3428 in 2019 (Table 1 and Figure 1B). Meanwhile, 103 countries and territories remained without a malaria episode from 1990 to 2019. Seven countries announced elimination of malaria in 2010, and five countries in 2015 announced elimination of malaria as well. China is the latest country to announce the elimination of malaria in 2017. Nevertheless, the ASRs increased in four countries and territories, with the largest increase in North Korea (EAPC = 26.07; 95% CI 7.94–47.24), followed by Cabo Verde (EAPC = 11.14; 95% CI 4.41–18.30), Venezuela (EAPC = 5.98; 95% CI 3.33–8.70) and Ethiopia (EAPC = 3.90; 95% CI 1.75–6.09). Notably, 40 countries had higher ASRs of malaria in 2019 than in 2015, with the largest expansion in Cabo Verde (from 2.02 per 100 000 to 597.00 per 100 000) and the smallest in Malawi (from 16 313.01 per 100 000 to 16 344.41 per 100 000).

Diversities in incidence of five SDI regions

There were considerable differences in malaria ASRs among the five SDI regions (Supplementary Figure S1). Higher SDI regions had significantly lower ASRs. In 2019, the ASR of high SDI regions was only 0.17 per 100 000, whereas it was 9763.37 per 100 000 in low SDI regions. The ASR decreased in all SDI regions by the most in high SDI regions (EAPC = −15.86; 95% CI −17.41–14.28) (Figure 3); however, there were uptrends in some SDI regions in specific years. After 2000, the ASRs in high-middle and middle SDI regions began to rise, which continued to 2010 and 2005, respectively. After 2015, the ASRs in high-middle, middle and low-middle SDI regions began to rise, and there were still uptrends until 2019. Trends of malaria episodes in the five SDI regions were similar with the ASRs (Figure 2).

In terms of age composition, globally, 65.70% of malaria episodes are composed of people under 15 years old in 2019. With the lower SDI, the proportion of infected people under 15 years old was higher, with 8.23% in high SDI regions and 68.84% in low SDI regions. On the other hand, the number of malaria episodes of people in the 15–49 years group accounted for a higher percentage with a higher regional SDI, 70.41% in high SDI regions and 29.19% in low SDI regions in 2019 (Figure 2).

Diversities in incidence of 21 GBD regions

Sub-Saharan Africa suffered from the severest malaria infection among all GBD regions. Central, Western and Eastern Sub-Saharan Africa had the highest ASRs since 1990, and their ASRs were 21 557.65 per 100 000, 19 092.54 per 100 000 and 10 839.40 per 100 000, respectively, in 2019 (Table 1). Five GBD regions (Australasia, Central Europe, Eastern Europe, Western Europe, high-income North America) had not reported any malaria episodes from 1990, and two more regions (Central Asia and Southern Latin America) had no malaria episodes in 2019. All the GBD regions had a decrease in the ASR from 1990 to 2019, with the largest decrease in Central Asia (EAPC = −38.71; 95% CI −43.91–33.03) (Figure 3). However, some regions (Central Latin America, Central, Eastern and Western Sub-Saharan Africa) had an increase in the number of malaria episodes (Table 1). It was probably related to the increase of population base in 30 years.

In 2019, >70% of malaria episodes were people in the 5–49 years group, and <20% were people under the age of 5 in most GBD regions. However, in Central, Western and Eastern

Table 1. The number of episodes and age-standardized incidence rates (ASR, per 100 000) of malaria infection in 1990 and 2019, and their temporal trends from 1990 to 2019

Characteristics	Number of episodes (thousands)			Age-standardized incidence rate		
	1990 (95% UI)	2019 (95% UI)	Change (%)	1990 (95% UI)	2019 (95% UI)	EAPC (95% CI)
Overall	242 785.69 (200 766.32–298 545.03)	231 357.37 (186 034.44–290 217.18)	−4.71	4084.08 (3388.02–4998.95)	3247.02 (2602.06–4109.56)	−0.80 (−1.02 to −0.58)
Sex						
Male	122 107.10 (100 985.21–150 825.05)	115 521.93 (92 858.51–145 186.43)	−5.39	4031.69 (3344.46–4965.67)	3164.05 (2537.39–4001.64)	−0.84 (−1.06 to −0.62)
Female	120 678.59 (99 805.49–147 456.47)	115 835.44 (93 179.67–145 027.55)	−4.01	4142.26 (3436.41–5050.01)	3334.43 (2666.85–4223.50)	−0.76 (−0.97 to −0.55)
Socio-demographic Index						
High	41.00 (23.31–77.94)	1.74 (0.26–6.91)	−95.76	4.99 (2.88–9.41)	0.17 (0.03–0.73)	−15.86 (−17.41 to −14.28)
High-middle	3211.29 (1813.52–6785.08)	1645.78 (984.94–2521.91)	−48.75	276.22 (155.49–588.00)	157.57 (90.50–252.34)	−2.12 (−3.13 to −1.10)
Middle	30 856.97 (24 383.54–42 103.06)	21 765.29 (14 757.29–31 137.61)	−29.46	1630.40 (1303.48–2202.20)	1031.78 (686.94–1490.84)	−2.14 (−2.62 to −1.65)
Low-middle	82 911.07 (62 948.88–119 453.85)	53 734.43 (42 023.67–69 855.62)	−35.19	6314.39 (4814.41–8882.81)	2945.63 (2299.00–3848.72)	−2.81 (−3.05 to −2.58)
Low	125 628.16 (101 791.72–149 837.52)	140 194.53 (112 975.72–176 902.60)	11.59	17 324.72 (14 158.03–20 551.63)	9763.37 (7952.71–12 017.48)	−1.61 (−1.87 to −1.35)
GBD region						
High-income Asia Pacific	26.24 (8.56–63.30)	0.55 (0.07–2.06)	−97.90	14.75 (4.81–35.60)	0.28 (0.04–1.06)	−14.16 (−15.7 to −12.59)
Central Asia	2348.14 (10.01–5110.76)	0	−100.00	2833.34 (14.77–5988.35)	0	−38.71 (−43.91 to −33.03)
East Asia	438.31 (304.95–1041.80)	9.86 (1.26–35.32)	−97.75	35.29 (24.69–83.61)	0.64 (0.08–2.31)	−14.14 (−15.78 to −12.47)
South Asia	58 523.29 (37 127.21–101 558.07)	12 234.65 (6579.01–22 083.79)	−79.09	5068.37 (3345.63–8330.42)	671.67 (361.09–1210.02)	−6.54 (−7.11 to −5.97)
Southeast Asia	6434.33 (4849.05–9392.89)	929.24 (362.06–2166.38)	−85.56	1368.78 (1058.55–1938.69)	134.47 (51.99–317.54)	−6.09 (−7.42 to −4.74)
Australasia	0	0	0	0	0	0
Caribbean	156.93 (119.85–255.29)	105.24 (40.31–261.85)	−32.94	432.42 (332.94–684.58)	222.76 (84.79–558.07)	−3.89 (−5.35 to −2.41)
Central Europe	0	0	0	0	0	0
Eastern Europe	0	0	0	0	0	0
Western Europe	0	0	0	0	0	0
Andean Latin America	1390.67 (730.18–3096.31)	107.06 (46.87–228.50)	−92.30	3649.72 (2041.16–7291.32)	168.14 (73.57–358.97)	−11.39 (−12.35 to −10.42)
Central Latin America	1636.99 (1452.76–1839.56)	1861.27 (497.16–5528.60)	13.70	1035.18 (923.88–1151.80)	741.47 (195.53–2222.14)	−5.61 (−7.6 to −3.58)
Southern Latin America	1.66 (1.66–1.66)	0	−100.00	3.40 (3.40–3.40)	0	−22.26 (−24.52 to −19.93)

Continued

Table 1. Continued

Characteristics	Number of episodes (thousands)			Age-standardized incidence rate		
	1990 (95% UI)	2019 (95% UI)	Change (%)	1990 (95% UI)	2019 (95% UI)	EAPC (95% CI)
Tropical Latin America	2046.71 (1765.74–2361.14)	259.75 (136.70–438.91)	−87.31	1238.89 (1077.91–1420.23)	115.40 (59.99–197.36)	−8.3 (−9.24 to −7.35)
North Africa and Middle East	5480.75 (3744.72–8739.91)	4123.77 (2384.23–7219.89)	−24.76	1355.72 (966.23–2063.13)	654.96 (379.22–1146.70)	−4.58 (−5.51 to −3.63)
High-income North America	0	0	0	0	0	0
Oceania	1416.68 (787.98–2357.93)	1169.05 (471.44–2399.19)	−17.48	18 802.45 (11 141.51–29 659.86)	8496.22 (3598.86–16 625.86)	−3.87 (−4.39 to −3.35)
Central Sub-Saharan Africa	25 168.12 (20 122.50–30 681.02)	38 038.03 (29 640.18–49 485.32)	51.14	30 614.03 (24 443.73–36 630.34)	21 557.65 (16 639.40–27 491.48)	−1.51 (−1.83 to −1.18)
Eastern Sub-Saharan Africa	52 496.04 (41 664.80–62 191.11)	56 431.81 (42 393.30–73 237.83)	7.50	19 159.86 (15 146.89–22 477.60)	10 839.40 (8233.31–13 780.92)	−2.29 (−2.59 to −1.98)
Southern Sub-Saharan Africa	1209.77 (811.08–2161.75)	915.32 (211.77–2930.84)	−24.34	2078.19 (1435.28–3631.05)	1126.40 (263.97–3598.29)	−3.27 (−4.55 to −1.96)
Western Sub-Saharan Africa	84 011.07 (67 844.25–101 886.19)	115 171.78 (89 000.69–152 717.49)	37.09	30 389.1 (24 508.25–37 164.36)	19 092.54 (14 859.41–24 474.70)	−1.61 (−1.88 to −1.33)

UI, uncertainty interval.

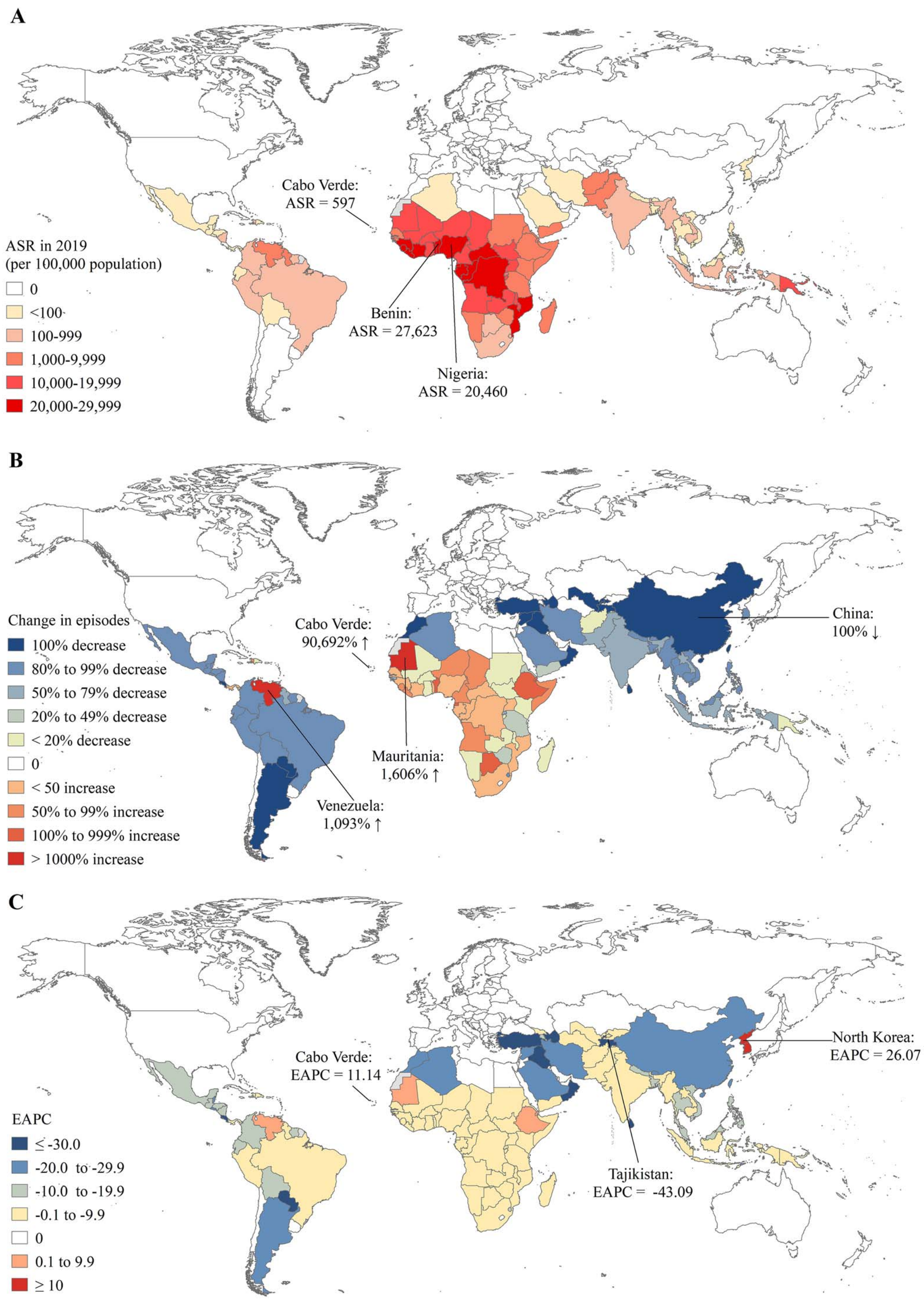

Figure 1. The global trends in incidence of malaria infection in 204 countries and territories. (A) The malaria ASRs in 2019; (B) changes in malaria episodes between 1990 and 2019; (C) the EAPCs of malaria ASRs from 1990 to 2019.

Sub-Sahara Africa, malaria episodes of people under 5 years old accounted for >30% (Supplementary Figure S3).

Change of traveller number from 2017 to 2018 and malaria ASRs in 2018

The traveller number increased by 89.56% from 1 514 000 in 2017 to 2 870 000 in 2018 in Mozambique, whose malaria ASR in 2018 was 22 070.51 per 100 000, higher than most other countries (Figure 4A). The traveller number increased by over 20% in Mali (malaria ASR: 12 784.35 per 100 000) and over 10% in Togo (malaria ASR: 21 476.79 per 100 000) and Sierra Leone (malaria ASR: 25 707.97 per 100 000) from 2017 to 2018. Benin, Cote d'Ivoire, Republic of the Congo, Burkina Faso, Malawi, Papua New Guinea and Solomon Islands also had slight increase in traveller number from 2017 to 2018. These

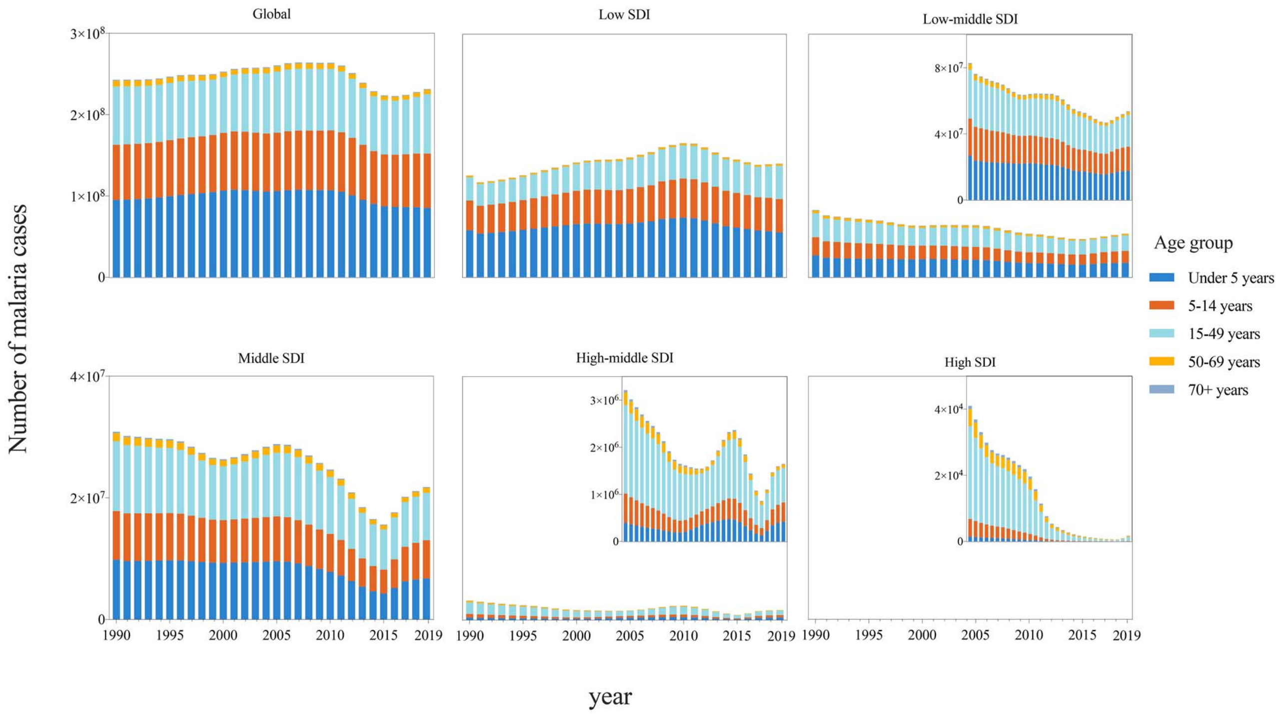

Figure 2. The number of malaria episodes by age group, by SDI region, from 1990 to 2019.

all countries had SDIs <0.5 and malaria ASRs over 10 000 per 100 000.

The traveller number in Western and Eastern Sub-Saharan Africa increased by 7.58 and 31.24%, respectively, from 2017 to 2018, with malaria ASR >10 000 per 100 000 in 2018 (Figure 4B).

Discussion

To the best of our knowledge, this is the first comprehensive effort to analyse the burden of malaria infection worldwide using data from the GBD 2019, assessing the global landscape, long-term trends and regional differences in incidence of malaria infection. Globally, despite a substantive decrease in malaria ASR from 1990 to 2019, the dramatical increase in malaria ASR from 2015 to 2019 alerted us that the fight against malaria remained challenging. Although the ASRs of all GBD regions and different SDI regions showed decreasing trends in the long term, three SDI regions (low-middle, middle and high-middle) had ASRs with increasing trends from 2015 to 2019. Meanwhile, the number of malaria episodes in 2019 significantly expanded in Central Latin America, Central Sub-Saharan Africa, Eastern Sub-Saharan Africa and Western Sub-Saharan Africa, compared with 1990. Facing with this complex situation of malaria, massive concerted and co-ordinated action need to be taken to eliminate malaria globally.

Our results showed that Sub-Saharan Africa suffered the severest threat of malaria infection. In 2019, total number of malaria episodes in Sub-Saharan Africa accounted for 91% of global malaria episodes, with the highest proportion in Nigeria (25%), followed by Congo (12%) and Uganda (5%). Previous studies showed the same situation with our study.[2,20] In Africa, the principal malaria vectors belong to the *Anopheles gambiae* complex and to the *Anopheles funestus* group,[21] several of which are among the world's most efficient malaria vectors and had longer life span and more human biting capacity, making the transmission of malaria easier and more sustainable in Africa.[20,22] In addition, increase in temperature and changes in rainfall patterns also resulted in a longer malaria season for many Sub-Saharan African regions.[23] Therefore, vector control plays an important role in the malaria prevention in Sub-Saharan African regions. Sleeping under an insecticide-treated net (ITN) and spraying the inside walls of houses with insecticide, an intervention known as indoor residual spraying (IRS), are the most commonly used vector-control interventions, which are considered to have made a major contribution to the reduction in malaria burden since 2000.[20,24] However, in Sub-Saharan Africa, percentage of population at risk sleeping under an ITN was 50% in 2018 and had not increased since 2016, and the percentage was even <40% in Angola, Liberia and Congo.[2] Meanwhile, during the past decade, vector control has relied heavily on pyrethroids, and today there is no country in Africa where the vectors remain fully susceptible to pyrethroids.[25,26] Despite the insecticide resistance, countries should also take action to increase the coverage of population sleeping under ITNs, on account of that ITNs can act as a physical barrier against parasite-carrying mosquitoes, and even a sub-lethal effect of the insecticide on mosquitoes may contribute to malaria control.[27]

The uptrends of malaria ASRs in high-middle, middle and low-middle SDI regions from 2015 to 2019 are unexpected, for the GTS was proposed in 2015, whose first milestone was set in 2020 to reduce malaria mortality rates and case incidence globally by at least 40%, compared with 2015.[8] The present study showed that 40 countries had higher ASRs of malaria in

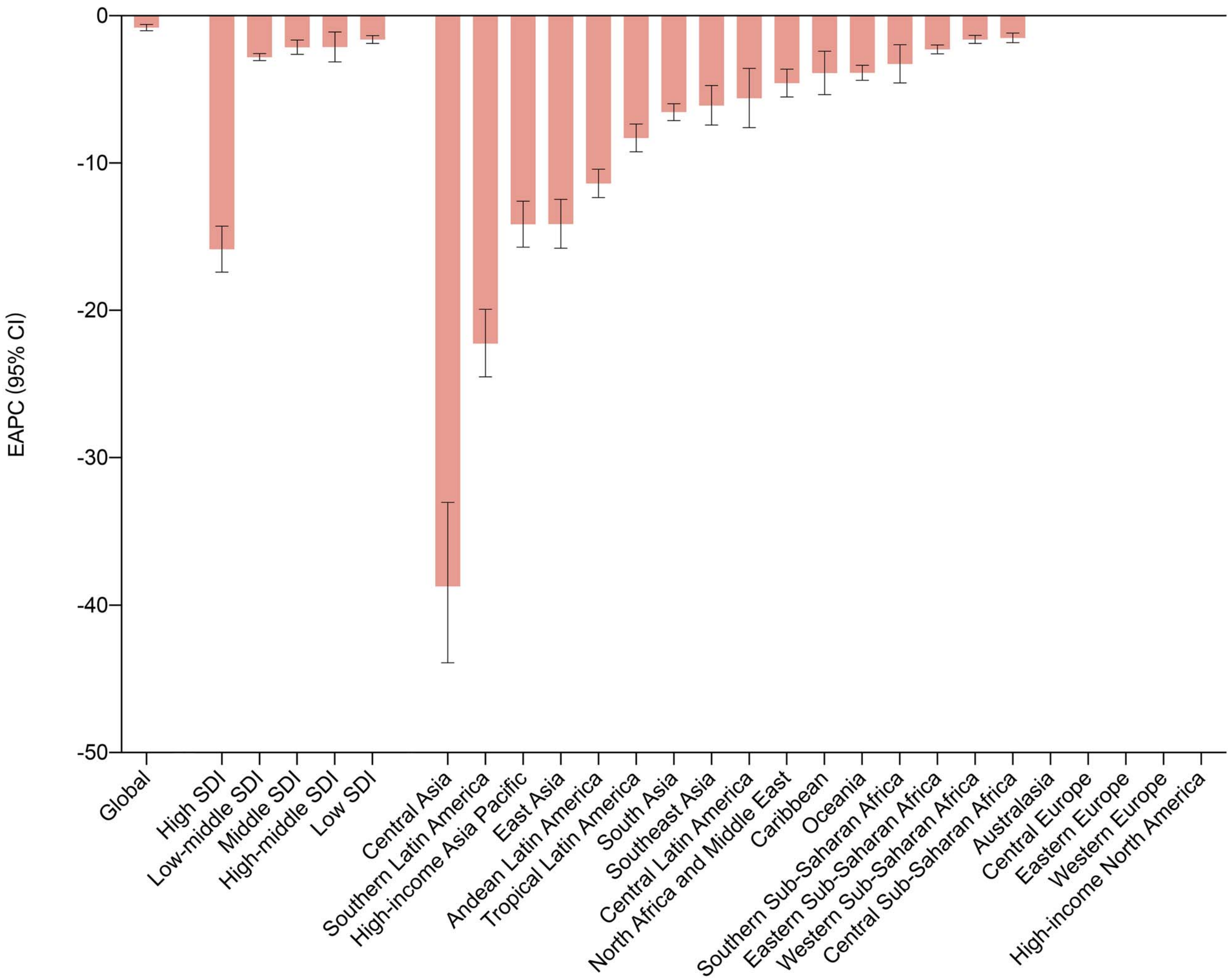

Figure 3. The EAPCs of malaria ASRs from 1990 to 2019 by GBD region.

2019 than in 2015, most of which are in Sub-Saharan Africa (Cabo Verde, South Africa, The Kingdom of eSwatini, etc.), followed by South America (Colombia, Ecuador, Venezuela, etc.) and South Asia (Pakistan and Afghanistan). Increase in *Pf*PR in African countries could partly explain the results.[10] *Plasmodium falciparum* is the most prevalent malaria parasite in African region, accounting for over 99% of estimated malaria episodes in 2018.[2] Moreover, adaptation of malaria vectors to the urban environments is now a real threat, despite the fact that urbanization could reduce malaria transmission earlier, with less clear water for the breeding site of *Anopheles* mosquito.[21,28,29] Countries in South America, which had higher ASRs in 2019 than in 2015, all have regions near or in the Amazon rainforest, in which malaria incidence increased due to the deforestation, proliferation of forest edges, standing water along forest margins and many other factors.[30,31] Most malaria episodes in Amazon rainforest areas are caused by *P. vivax*, and it has re-emerged since 2015 in locations that had not experienced intense malaria infection since the 2010 epidemic (Amazon Basin and Central Pacific).[32,33] In addition, transnational transmission of malaria among these countries has been reported; about 78 and 81% of Brazil and Colombia malaria-imported cases, respectively, are estimated to come from Venezuela.[32] Therefore, concerted efforts by Amazon countries in the region are needed for malaria control. In Pakistan, socio-environmental factors play an important role in shaping the malaria dynamics.[34] Discovering local malaria dynamics through the spatial statistical analysis will help to devise evidence-based, most appropriate strategies to reduce malaria risk in the region.[34]

Children under the age of 5 are the most vulnerable group affected by malaria. Their incidence rate of malaria was the highest among all age groups. In high-transmission areas, the main burden of malaria, including all malaria-related deaths, is borne by young children[35]; they accounted for 67% of all malaria deaths worldwide in 2018.[2] Our results also showed that malaria episodes of people under 5 years accounted for >30% in Central, Western and Eastern Sub-Sahara Africa. Children under 5 are facing compound healthy problems besides malaria. Higher anaemia prevalence was observed among children infected with malaria than among those who were not.[2] In Sub-Saharan countries, malaria occurs in children who are already weakened by parasitic, viral and bacterial infections, nutritional deficiencies and genetic conditions.[9] Therefore, interventions for children under 5 years to prevent malaria are required, especially in

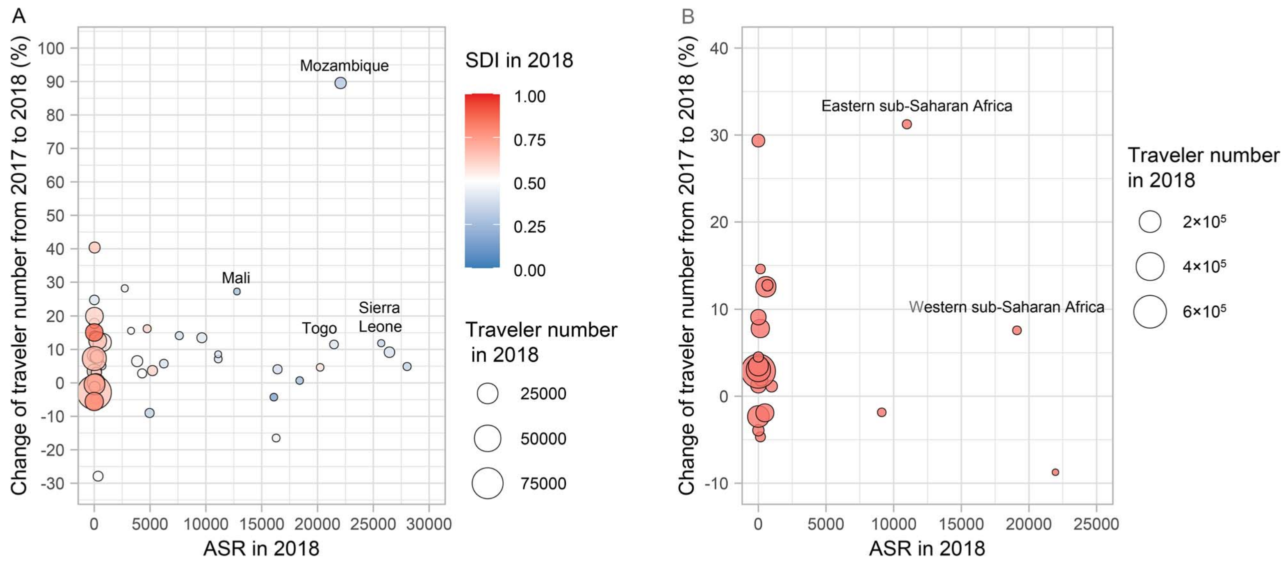

Figure 4. Change of traveller number from 2017 to 2018. (A) Change of traveller number from 2017 to 2018 in different countries∗ with ASRs and SDI in 2018. (B) Change of traveller number from 2017 to 2018 in GBD regions with ASRs in 2018. ∗The following countries lack data to calculate the change of traveller number: Liberia, Central African Republic, The Democratic Republic of the Congo, Uganda, Gabon, Guinea, Equatorial Guinea, Nigeria, Cameroon, South Sudan, Ghana, Burundi, Chad, Zambia, Mauritania, Kenya, Somalia, Guinea-Bissau, Senegal, Rwanda, Djibouti, Venezuela, Yemen, Eritrea, Afghanistan, Pakistan, Suriname, North Korea and Bangladesh.

Sub-Saharan African countries. For children and other high-risk groups, WHO recommends vector control or chemoprevention for the prevention of malaria.[2] Intermittent preventive treatment in infants with sulphadoxine–pyrimethamine (SP) and seasonal malaria chemoprevention (SMC) with amodiaquine plus SP in children under 5 years have been shown to reduce the incidence of malaria.[36,37] In addition, malaria vaccine could serve as a choice for malaria prevention. RTS,S/AS01 (RTS,S), acting against *P. falciparum*, is the first and only vaccine that can significantly reduce malaria and life-threatening, severe malaria in young African children.[38]

In addition, school-age children aged 5–15 years require more attention. A total of 200 million school-age children are at risk of malaria in Africa, in many areas of which the prevalence of infection exceeds 50% in this age group.[39] School-age children with malaria infections are also an important source of human-to-mosquito *P. falciparum* infection.[40] School-based interventions, such as the preventive malaria treatment, benefit children across all levels of malaria transmission, including geographic areas with very low (3%) to very high (67%) parasite prevalence.[39]

Our results also showed that many countries had eliminated malaria during last decades, and China is the latest country to announce the elimination of malaria in 2017. We can learn from the experience of China to help malaria-endemic countries formulate strategies to fight against malaria. The '1-3-7' approach to malaria surveillance and response was a key measure for malaria elimination in China that aims to have all cases of malaria reported within 1 day, case investigation conducted within 3 days and an in-depth investigation conducted within 7 days.[41] This approach was also introduced by WHO to be a guideline to instruct malaria control programmes worldwide, especially in countries or regions where malaria is close to elimination.[42] It was demonstrated that the malaria burden could be reduced by 81% when China's experience with malaria control was shared in Tanzania through interactions between health officials from China and Tanzania.[43] Surveillance is a core intervention and the basis of operational activities in settings of any level of transmission, with an objective for supporting reduction of the burden of malaria, eliminating the disease and preventing its re-establishment.[8,42] However, capacity for vector surveillance and control is insufficient in most countries at risk from mosquito-borne diseases.[44] Furthermore, many countries that are endemic for more than one major mosquito-borne disease have disease-specific programmes and strategies that do not optimally promote synergies, and sometimes compete for resources.[44] These countries require surveillance systems that can accurately and reliably track the burden of malaria, the interventions to reduce it, and the impact achieved geographically and temporally.

Globalization has increasingly created a huge migration flow and mobile populations, which cause a high risk of disease spreading. Our results showed that the number of travellers visiting tropical areas continued to rise, especially in areas where malaria ASRs were high and malaria transmission might occur, such as Western and Eastern Sub-Saharan African countries, like Mozambique, Mali, Togo, Sierra Leone, etc. The prevalence of malaria in different areas was shown in our results, and people can consider what preventive measures should be taken before travelling.[45] For those travelling to malaria-endemic areas, such as Sub-Saharan Africa, malaria can be prevented effectively through protection against mosquito bites and through chemoprophylaxis; however, non-compliance rates of malaria chemoprophylaxis are considerable in travellers.[45] When travelling to areas with very low rates of malaria incidence, such as Southeast Asia and North America, preventing malaria by avoiding mosquito bites becomes more rational, rather than through chemoprophylaxis, considering the efficacy, tolerability and safety of chemoprophylaxis.[46] For countries where malaria was eliminated, the threat of imported malaria will remain for a long time.[47] Therefore, the sensitivity and effectiveness of the surveillance and response system against malaria need to be maintained.

Currently, the rapid emergence and spread of coronavirus disease 2019 (COVID-19) across the world has created massive global disruptions that are impacting people's lives and well-being.[48] Although taking measures to tackle COVID-19, malaria should not be ignored. During the COVID-19 pandemic, the malaria community must remain committed to supporting the prevention of malaria infection, illness and death through preventive and case management services, while maintaining a safe environment for patients, clients and staff.[49] Such measures are also a key strategy for reducing the strain on health systems when an extra burden is anticipated due to COVID-19.[50]

In conclusion, although there was a significant decrease in malaria incidence since 2000, it is still a public health threat in areas where malaria is endemic, especially in Sub-Saharan African countries, which had an expansion of malaria episodes in 2019, compared with 1990. Immediate actions are needed to reverse the uptrends of malaria ASRs since 2015 in high-middle, middle and low-middle SDI regions. Countries, such as South Africa, Colombia, Pakistan, etc., which had higher malaria ASRs in 2019 than in 2015 should attach great importance on malaria control. Children under 5 years are the most vulnerable group and require more attention, and school-age children should not be ignored as well. When travelling to malaria-endemic areas, take preventive measures according to the local malaria epidemic level. The population-level coverage of interventions for preventing malaria, such as ITNs, IRS and SMC, should be enlarged. Generally speaking, we should take targeted measures for different groups of people in different countries and territories. More study focusing on malaria needs to be done for global to achieve the goal of malaria elimination.

Supplementary Data

Supplementary data are available at *JTM* online.

Authors' Contributions

M.L. (liumin@bjmu.edu.cn) and J.L. (jueliu@bjmu.edu.cn) contributed equally as correspondence authors. M.L. and J.L. conceived and designed the manuscript. Q.L. did a literature search, analysis and interpretation, compiled tables and figures, and drafted the manuscript. W.J. and J.L. proofed and interpreted the report. All authors participated in data analysis, interpretation, discussion and writing of the manuscript.

Acknowledgement

The authors appreciate the works by the Global Burden of Disease Study 2019 collaborators.

Funding

This work was supported by the grant from National Natural Science Foundation of China (No. 71934002), the National Key Research and Development Project of China (grant numbers 2020YFC0846300 and 2020YFC0849500) and the National Science and Technology Key Projects on Prevention and Treatment of Major Infectious Disease of China (grant number 2020ZX10001002). The funders had no role in study design, data collection and analysis, decision to publish or preparation of the paper. No payment was received by any of the co-authors for the preparation of this article. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Conflict of Interest

None declared.

Ethical Approval

Not applicable.

Informed Consent

Not applicable.

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