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*Original Article*

# The past, present and future of global malaria and neglected tropical diseases: a disease burden assessment from 1990 to 2030

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## Abstract

Introduction: The World Health Organization (WHO) plans to control the epidemics of malaria and neglected tropical diseases (NTDs) by 2030. The aim of this study was to evaluate the realizability of achieving the WHO targets by assessing the past, present, and future global disease burden of malaria and NTDs.

Methodology: Joinpoint regression, Spearman's correlation, and the autoregressive integrated moving average model (ARIMA) were used to estimate the trends of malaria and NTDs from 1990 to 2030 based on the Global Burden of Disease (GBD) Study 2019.

Results: Western Sub-Saharan Africa had the highest cases of malaria and NTDs in 2019, with one-half of the global cases. The age-standardized incidence rate (ASIR) in high socio-demographic index (SDI) and World Bank high-income regions showed upward trends from 1990 to 2019. The highest burden of NTDs was dengue in 2019, and the ASIR of dengue showed an obvious upward trend from 1990 to 2019. Children (< 5 years) had the most serious disease burden of malaria and NTDs from 1990 to 2019. The predicted results showed that the age-standardized mortality rate of malaria and NTDs worldwide had a slow upward trend from 2020 to 2030.

Conclusions: This analysis emphasizes that the control of malaria and NTDs in western sub-Saharan Africa should be continuously strengthened and the resurgence of malaria and NTDs in high SDI and World Bank high-income regions needs to be highlighted. Dengue and children (< 5 years) are the primary diseases and populations of concern, respectively, for future prevention efforts.

**Key words:** malaria; NTDs; GBD; assessment; prediction.

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## Introduction

Tropical diseases are a large group of infectious diseases caused by viruses, bacteria, and parasites, which are usually prevalent in tropical and subtropical regions [1]. Infectious tropical diseases mainly include malaria and neglected tropical diseases (NTDs). Malaria is a common and severe tropical disease. According to the World Health Organization (WHO), malaria affects approximately 247 million people and kills more than 600,000 people worldwide each year; and is especially serious in sub-Saharan Africa [2–4]. The current effective treatment of malaria is mainly standard artemisinin combination therapy (ATC) [5]. However, it is unfortunate that ATC resistance has emerged in some countries and areas in recent years, which makes malaria control and elimination more difficult and poses a serious threat to human health [6,7]. NTDs are another group of tropical diseases that should not be overlooked, and mainly includes 20 types of diseases [8–10]. It is estimated that more than 1 billion people are affected by NTDs worldwide, and about 1.7 billion people need preventive treatment each year. The total disease burden of NTDs is equivalent to AIDS, tuberculosis, or malaria; and most of the NTDs carry the risk of causing disability and disfigurement [11–14]. Residents of economically underdeveloped areas cannot get timely and effective prevention and treatment due to limited health resources, which makes the prevalence of NTDs persistent and difficult to control.

Evidence suggests that the spatial location of malaria and NTDs is highly consistent; therefore, co-infection of the two diseases is very common [15–17]. Co-infection of malaria and NTDs will worsen the patient's condition and elevate mortality. For example, it was reported that children in Kenya who were co-infected with the two diseases had lower hemoglobin than those who were infected with only one disease

[18]. Moreover, controlling and eliminating malaria and NTDs can be challenging [19]. Although unprecedented breakthroughs have been made in the global fight against malaria and NTDs in recent years, a variety of factors such as climate change, emerging infectious diseases, increasing drug resistance, socioeconomic inequalities, and uneven distribution of health resources have reduced the effectiveness of the previous solutions to control and eliminate malaria and NTDs [20]. Therefore, it is possible to get better health benefits by combining the control and prevention of malaria and NTDs and integrating the solutions for them [21–24].

Although a limited number of studies have assessed the global burden of malaria and NTDs, the diseases were individually included in these studies [25,26]. However, it is worth noting that malaria and NTDs are the two most important tropical diseases and their incidence, mortality and disease burden account for a large proportion of all tropical diseases. Therefore, combining malaria and NTDs can provide information on the development trend and disease burden of major tropical diseases worldwide.

In this study, the trend in the incidence, mortality, and disease burden of malaria and NTDs in different countries and regions from 1990 to 2019 were quantitatively evaluated. This analysis can help to further understand the changes in major tropical diseases over the past three decades. Secondly, the trends of burden due to malaria and NTDs in regions and populations with different characteristics were analyzed, which helped to identify high-risk groups and regions with high disease burden. This information can guide the direction of future targeted management of malaria and NTDs in the world. Thirdly, the disease burden of malaria and different types of NTDs were compared and the changes in disease burden over each decade were analyzed to provide clues for the detection of diseases with severe disease burden at different periods. Finally, the data on the disease burden of malaria and NTDs in 204 countries worldwide from 1990 to 2019, was used to predict the disease burden from 2020 to 2030, and assess the realizability of achieving the WHO goal for controlling malaria and NTDs by 2030. Meanwhile, the predicted results can also provide a reference for advanced intervention of malaria and NTDs. The aim of this study was to add new insights to this field and help the global efforts to eliminate malaria and NTDs by 2030.

## Methodology

*Data sources*

The data used in this study were obtained from the Global Burden of Disease Study 2019 (GBD 2019) [27], which included incidence, mortality and disease burden of malaria and NTDs for 204 countries and territories from 1990 to 2019. The NTDs included in this study were Chagas disease, leishmaniasis, African trypanosomiasis, schistosomiasis, cysticercosis, cystic echinococcosis, lymphatic filariasis, onchocerciasis, trachoma, dengue, yellow fever, rabies, intestinal nematode infections, food-borne tremors, leprosy, Ebola, Zika virus, guinea worm disease, and other NTD. Disability-adjusted life years (DALYs) were defined as years of healthy life lost from incidence to death, including years of life lost due to premature death (YLL) and years of healthy life lost due to disability (YLD). Socio-demographic index (SDI) is a comprehensive indicator of the development in a country or region, which is assessed by combined data on the overall fertility rate of women under 25 years of age, the average level of education of women 15 years and older, and the per capita income. SDI values range from 0 to 1, with an SDI of 0 representing the lowest level of health development and an SDI of 1 representing the highest level of health development.

*Statistical analysis*

First, the incidence, mortality, and disease burden of malaria and NTDs in different regions and countries were collated and the trend change of age-standardized rate (ASR) from 1990 to 2019 was calculated using joinpoint regression. The average annual percentage change (AAPC) was used to represent the trend change over time, and the formula used was:

$$AAPC = \{exp\left(\frac{\sum w_i b_i}{\sum w_i}\right) - 1\} \times 100$$

where $b_i$ represented the coefficient of slope in the $i$-th segment, $i$ represented each segment within the required year range, and $w_i$ represented the length of each period. An AAPC > 0 and $p < 0.05$ indicated an increasing trend in the change of ASR within the year range and vice versa.

Second, the changes in the burden of malaria and NTDs for different characteristic regions and populations from 1990 to 2019 were analyzed and stratified by gender, age, level of social development, and World Bank income region.

Third, the disease burden of malaria and different types of NTDs were compared and the trends in ASR for different diseases in each decade were analyzed.

Fourth, a generalized additive model was used to analyze the association of SDI with ASR and its AAPC in 204 countries and regions, and Spearman's correlation was used to explore the correlation between them.

Finally, the autoregressive integrated moving average model (ARIMA) was used to predict the disease burden from 2020 to 2030 based on the GBD 2019 data to explore the future trend of malaria and NTDs in regions and populations with different characteristics.

In this study, Joinpoint 4.9.1.0 was used for joinpoint regression analyses; R 4.2.0 was used for Spearman's correlation analysis ("Hmisc" package) and trend prediction ("tseries", "forecast" and "zoo" packages); ArcGIS Map 10.7 was used for generating statistical maps; and GraphPad Prism 8 was used for line and bar charts. All statistical tests were two-sided and differences were considered significant when $p < 0.05$.

## Results

*Global burden of malaria and NTDs in 2019*

Approximately 290 million people were infected by malaria and NTDs worldwide in 2019, which was a 4.69% increase compared with 1990 (Table 1). The burden of malaria and NTDs was highest in the low SDI region in 2019. Meanwhile, the corresponding age-standardized incidence rate (ASIR) in high-middle SDI and high SDI regions increased compared to 1990, and their AAPC was 1.26 (95% CI: 0.99 to 1.53) and 1.41 (95% CI: 1.18 to 1.64), respectively. In the GBD region, Western Sub-Saharan Africa had the highest number of cases of malaria and NTDs in 2019, with half of the global incidence. At the same time, the number of cases (growth rate: 36.61%) and DALYs (growth rate: 15.54%) in this region increased compared to 1990.

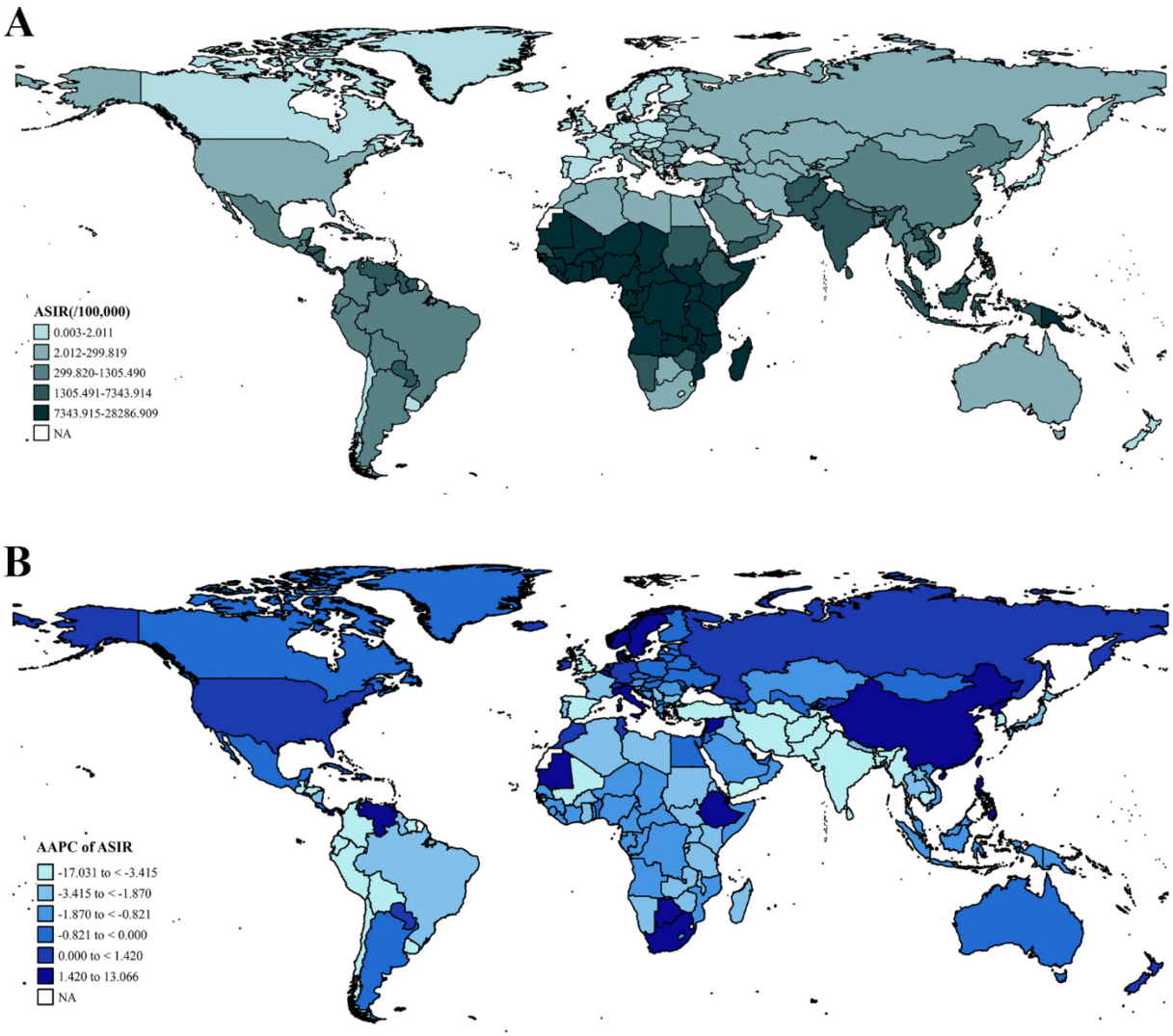
In 2019, the country with the highest ASIR of malaria and NTDs was Benin (28286.908 [95% uncertainty interval (UI): 22650.606 to 35706.908]/100,000) and the lowest was Finland (0.003 [95% UI: 0.001 to 0.005]/100,000) (Figure 1); the highest age-standardized mortality rate (ASMR) was Sierra Leone (168.260 [95% UI: 67.193 to 295.517]/100,000) and the lowest was Ireland (0.004 [95% UI: 0.001 to 0.006]/100,000) (Supplementary Figure 1); and the highest age-standardized disability-adjusted life rate (ASDR) was Sierra Leone (9534.948 [95% UI: 4397.164 to 15842.600]/100,000) and the lowest was Ireland (2.271 [95% UI: 1.233 to 4.010]/100,000) (Supplementary Figure 2). The ASIR, ASMR, and ASDR of most countries changed in 2019 compared to 1990. The decreases in the ASIR, ASMR, and ASDR of malaria and NTDs were the most in Comoros (AAPC: – 17.031 [95% CI: – 26.884 to – 5.851]), Cook Islands (AAPC: – 18.71 [95% CI: – 18.97 to – 18.46]), and Bhutan (AAPC: – 12.65 [95% CI: – 13.86 to – 11.43]). The ASIR and ASMR of malaria and NTDs increased the most in the Democratic People's Republic of Korea (AAPC: 13.07 [95% CI: – 2.52 to 31.15]) and Barbados (AAPC: 4.51 [95% CI: 3.33 to 5.71]).

**Table 1.** Number of malaria and NTDs cases, along with ASIR, and AAPC.

| Characteristics | 1990 | | 2019 | | AAPC of ASIR (95% CI) |
|---|---|---|---|---|---|
| | Number of cases (95% UI) | ASIR/100,000 (95% UI) | Number of cases (95% UI) | ASIR/100,000 (95% UI) | |
| Total | 276737307.00 (223626967.10, 339311683.30) | 4703.20 (3793.02, 5747.54) | 289730012.80 (230991843.80, 364945572.00) | 4006.85 (3186.96, 5066.98) | -0.56 (-0.66, -0.45) |
| Male | 138573286.19 (112254221.56, 170301864.89) | 4628.62 (3735.45, 5688.00) | 143727448.92 (115424532.79, 180623827.99) | 3895.16 (3117.17, 4912.97) | -0.60 (-0.70, -0.49) |
| Female | 138164020.84 (111466109.30, 168547890.85) | 4785.70 (3855.83, 5851.61) | 146002563.91 (115725853.88, 184349574.90) | 4124.41 (3268.83, 5229.16) | -0.51 (-0.64, -0.38) |
| High-middle SDI | 5871726.69 (3604850.13, 10685171.20) | 506.70 (310.37, 926.14) | 8889136.79 (5109302.61, 13407534.51) | 700.17 (407.38, 1081.99) | 1.26 (0.99, 1.53) |
| High SDI | 497943.47 (409825.75, 600085.74) | 63.09 (50.98, 76.46) | 916747.21 (612433.52, 1308999.45) | 93.38 (63.46, 133.07) | 1.41 (1.18, 1.64) |
| Low-middle SDI | 98601714.80 (69633565.42, 142304606.70) | 7715.04 (5441.49, 11095.55) | 83434782.33 (58774307.73, 120880205.80) | 4624.28 (3236.91, 6760.14) | -1.74 (-1.85, -1.64) |
| Low SDI | 131020331.00 (106467842.00, 155176976.10) | 18442.41 (15199.66, 21634.38) | 154143525.10 (124291348.80, 193808159.90) | 10900.99 (8867.34, 13432.64) | -1.79 (-1.94, -1.64) |
| Middle SDI | 40586859.48 (31416351.85, 53789887.74) | 2193.06 (1705.38, 2882.16) | 42190299.73 (31972129.21, 60198162.52) | 1903.97 (1416.10, 2718.74) | -0.40 (-0.68, -0.12) |
| Andean Latin America | 1640161.83 (963169.23, 3378428.52) | 4306.45 (2658.78, 8035.53) | 638012.91 (526565.88, 787342.38) | 998.92 (829.38, 1234.01) | -4.77 (-6.37, -3.15) |
| Australasia | 37616.56 (5346.48, 97526.32) | 185.80 (25.64, 483.23) | 55245.03 (10404.85, 136164.16) | 188.67 (34.26, 466.32) | 0.05 (0.02, 0.08) |
| Caribbean | 443448.89 (323565.87, 606305.79) | 1254.86 (935.72, 1687.09) | 463739.07 (262966.15, 716357.13) | 980.27 (552.15, 1518.80) | -0.93 (-1.35, -0.50) |
| Central Asia | 2425889.51 (77792.96, 5180445.77) | 2953.92 (121.18, 6097.53) | 99831.93 (61636.72, 156750.42) | 105.39 (65.75, 164.22) | -10.85 (-11.44, -10.27) |
| Central Europe | 3722.58 (2933.63, 5206.65) | 3.04 (2.38, 4.37) | 2413.23 (2078.95, 2782.84) | 1.85 (1.57, 2.15) | -1.69 (-1.74, -1.64) |
| Central Latin America | 2903370.32 (2693913.25, 3136089.72) | 1816.76 (1676.85, 1965.48) | 4037391.88 (2515538.76, 7705337.61) | 1607.53 (1002.78, 3083.74) | -1.23 (-1.95, -0.51) |
| Central Sub-Saharan Africa | 25573608.57 (20606719.63, 30954740.71) | 31355.95 (25274.17, 37266.86) | 38750750.07 (30271137.00, 49772708.98) | 22121.25 (16935.80, 28318.17) | -1.15 (-1.46, -0.84) |
| East Asia | 2268975.84 (1879232.80,2924055.32) | 185.18 (153.99,237.38) | 6731434.83 (2415889.22,12639754.95) | 495.59 (174.59, 943.28) | 3.53 (2.82, 4.25) |
| Eastern Europe | 23826.40 (19689.29, 28338.16) | 9.49 (7.92, 11.21) | 24610.09 (20328.38, 29428.89) | 9.69 (8.15, 11.48) | 0.07 (0.06, 0.08) |
| Eastern Sub-Saharan Africa | 54406349.44 (43348069.56, 63945999.28) | 20387.61 (16370.84, 23840.41) | 58051705.49 (43613476.66, 74657766.93) | 11233.34 (8525.97, 14305.03) | -1.96 (-2.17, -1.74) |
| High-income Asia Pacific | 57095.87 (33596.54, 94328.08) | 32.75 (18.92, 54.31) | 62669.85 (47849.77, 84671.48) | 37.07 (27.31, 51.28) | 0.34 (-0.57, 1.26) |
| High-income North America | 14437.57 (10629.60, 18186.75) | 5.03 (3.60, 6.42) | 25723.38 (19003.11, 32466.03) | 6.70 (4.87, 8.63) | 1.01 (0.68, 1.33) |
| North Africa and Middle East | 6208858.43 (4437032.55, 9503869.54) | 1565.67 (1161.99, 2258.95) | 5303659.86 (3052371.38, 8396988.62) | 848.58 (489.32, 1342.11) | -2.21 (-2.40, -2.02) |
| Oceania | 1480006.79 (858374.39, 2422490.92) | 19814.70 (12174.09, 30794.31) | 1585771.76 (662789.20, 3013678.32) | 11671.91 (5042.26, 21086.46) | -1.32 (-2.28, -0.35) |
| South Asia | 76943981.83 (45035120.66, 128172494.60) | 6761.65 (4075.72, 11003.22) | 43553618.09 (19752557.34, 88438419.26) | 2416.66 (1080.84, 4904.92) | -3.50 (-3.59, -3.40) |
| Southeast Asia | 11329624.76 (8046746.78, 19025899.32) | 2407.48 (1741.37, 3993.14) | 8641502.30 (7688072.93, 10056333.99) | 1289.54 (1149.96, 1500.62) | -1.86 (-2.14, -1.57) |
| Southern Latin America | 135010.46 (68479.84, 247163.84) | 267.91 (133.98, 494.47) | 136965.01 (58993.50, 273387.57) | 206.71 (88.04, 414.74) | -0.86 (-1.05, -0.67) |
| Southern Sub-Saharan Africa | 1243202.52 (845606.42, 2199591.78) | 2138.13 (1494.87, 3675.58) | 954332.52 (243653.22, 2984730.81) | 1175.21 (303.65, 3614.37) | -2.50 (-2.84, -2.17) |
| Tropical Latin America | 3311427.65 (2737375.02, 3926010.66) | 2067.84 (1716.43, 2438.55) | 2732486.36 (2410555.48, 3065503.60) | 1212.41 (1082.35, 1345.72) | -1.79 (-2.34, -1.24) |
| Western Europe | 1747.48 (1460.50, 2149.33) | 0.48 (0.40, 0.59) | 5301.46 (4547.09, 6153.65) | 1.05 (0.90, 1.21) | 2.50 (1.98, 3.03) |
| Western Sub-Saharan Africa | 86284943.73 (69968379.82, 104234922.42) | 31731.82 (25898.93, 38570.53) | 117872847.71 (90855055.47, 154907383.71) | 19714.88 (15432.93, 25324.66) | -1.63 (-1.75, -1.52) |

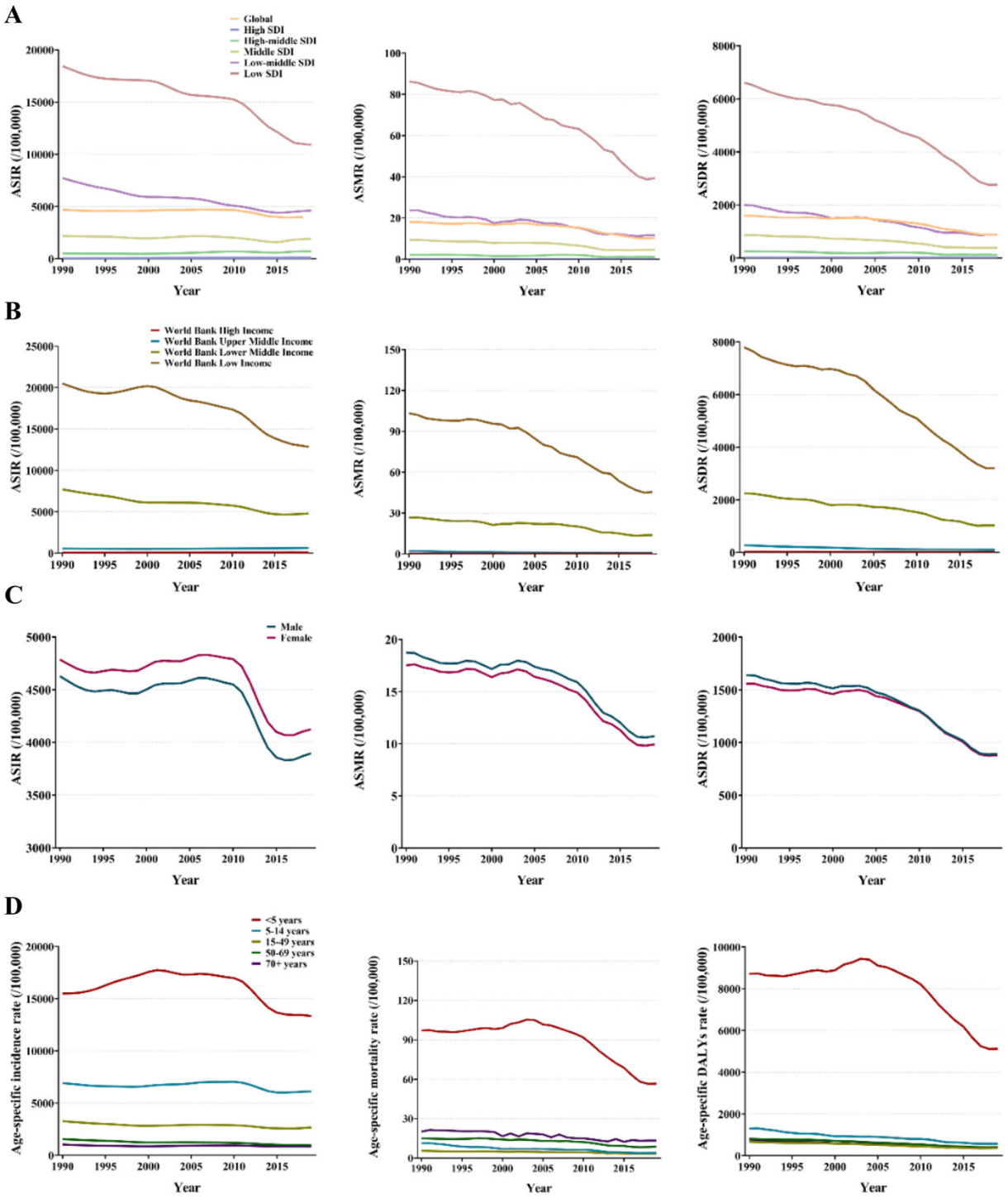
AAPC: average annual percentage change; ASIR: age-standardized incidence rate; GBD: global burden of disease; NTDs: neglected tropical diseases; SDI: socio-demographic index.

**Figure 1 A.** Global ASIR in 2019; **B.** AAPC from 1990 to 2019.




ASIR: age-standardized incidence rate; AAPC: average annual percentage change.

**Figure 2.** The trends in ASIR, ASMR, and ASDR of malaria and NTDs from 1999 to 2019.




**A:** disease burden of malaria and NTDs in the SDI regions from 1999 to 2019; **B:** disease burden of malaria and NTDs in World Bank income regions from 1999 to 2019; **C:** disease burden of malaria and NTDs by gender from 1999 to 2019; **D:** disease burden of malaria and NTDs by age from 1999 to 2019. ASIR: age-standardized incidence rate; ASMR: age-standardized mortality rate; ASDR: age-standardized disability-adjusted life years rate; NTDs: neglected tropical diseases.

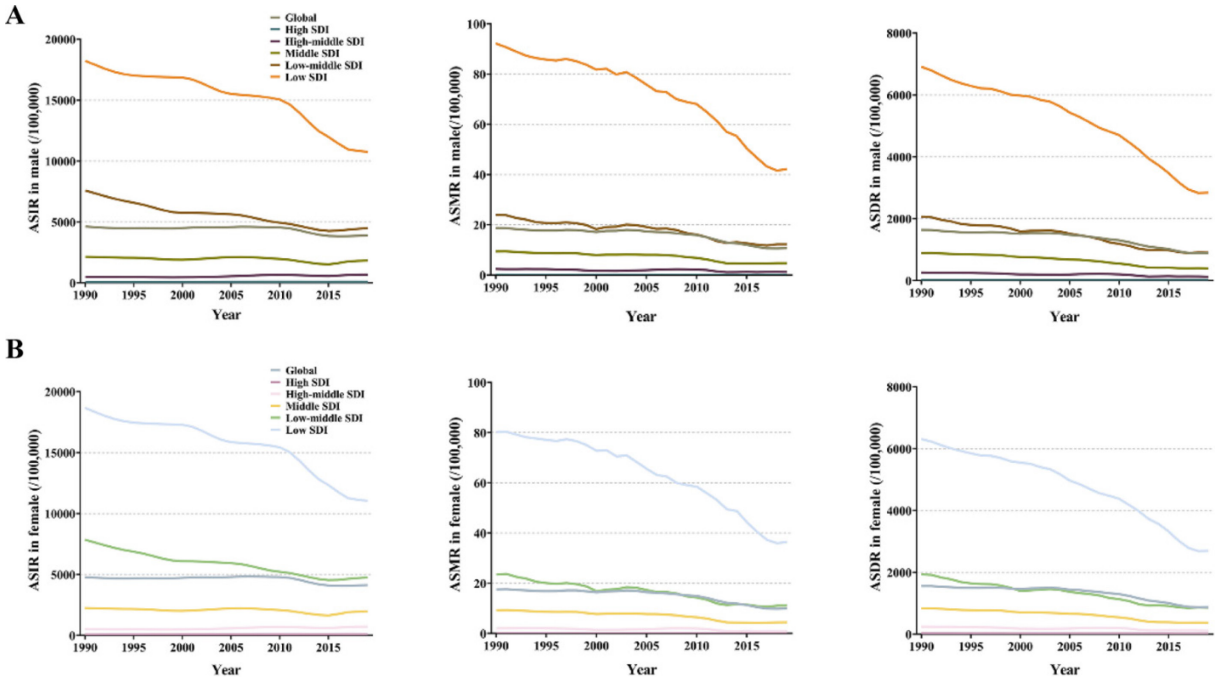
*Trend analysis of malaria and NTDs burden from 1990 to 2019*

The global ASIR, ASMR, and ASDR of malaria and NTDs changed little from 1990 to 2019; however, the corresponding number of deaths (growth rate: – 38.37%) and DALYs (growth rate: – 50.11%) showed significant downward trends (Supplementary Tables 1 and 2). Among the SDI regions, the ASIR, ASMR, and ASDR of malaria and NTDs were the highest in the low SDI region and the lowest in the high SDI region. The decreases in the ASIR, ASMR, and ASDR from 1990 to 2019 were the most in the low SDI region; but the corresponding number of cases, deaths, and DALYs changed little over time (Figure 2 and Supplementary Figure 3). Among the World Bank income regions, the ASIR, ASMR, and ASDR of malaria and NTDs were the highest in the low-income region and the lowest in the high-income region. However, the number of cases, deaths, and DALYs were the highest in the lower middle-income region and the corresponding number of deaths and DALYs showed a significant downward trend from 1990 to 2019. Among populations of different ages, the highest incidence, mortality, and DALYs burden of malaria and NTDs were under 5 years of age, and showed obvious downward trends from 1990 to 2019. Among populations of different genders, males and females had similar trends in disease burden within different ages and regions, showing large declines, and the ASMR and ASDR were slightly higher for males than females (Figure 3, Supplementary Figures 4, 5, 6, 7, 8).

*Comparison of the burden of malaria and different types of NTDs*

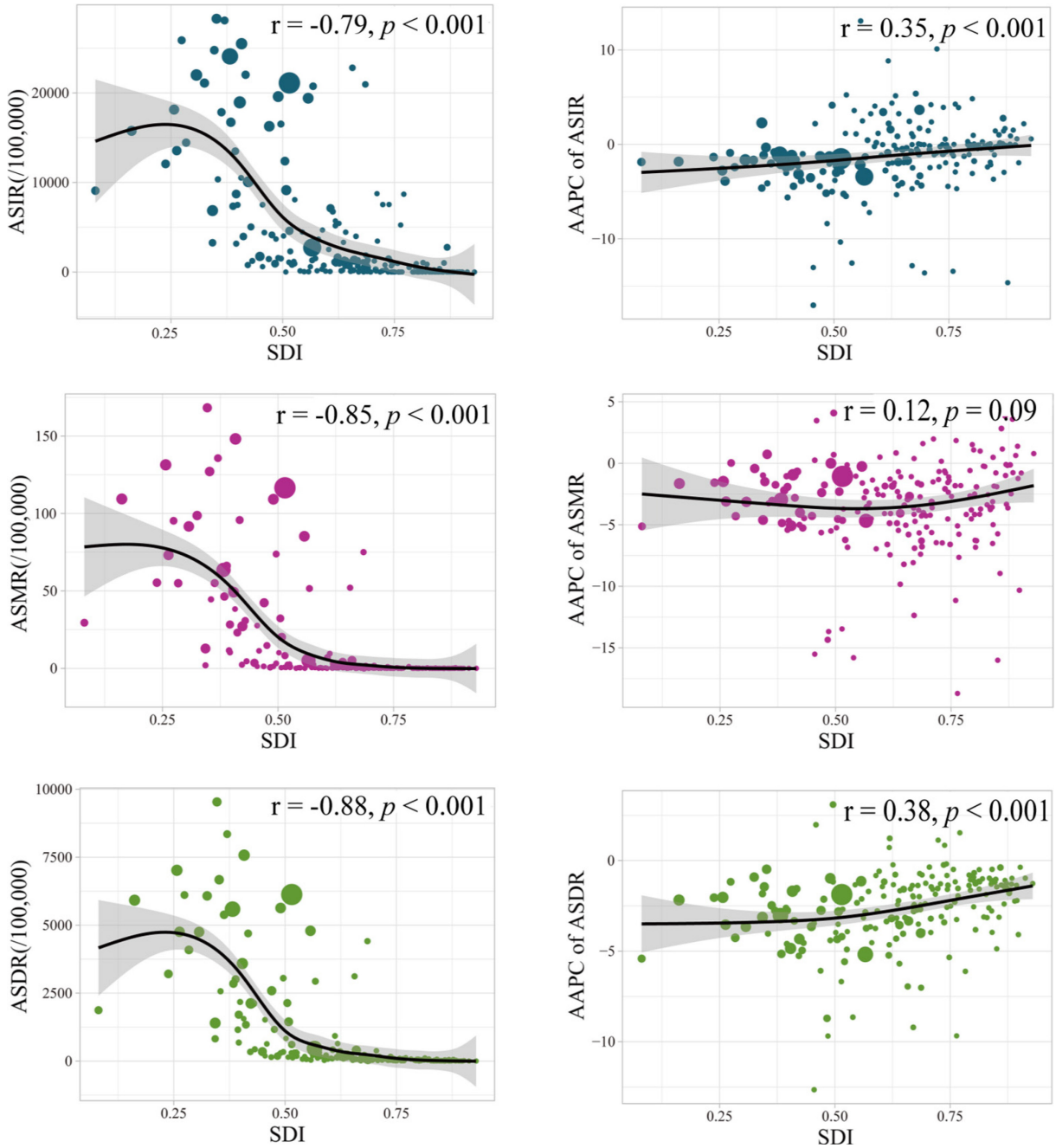
The burden of malaria was the most severe of all diseases in the study, with a decreasing trend in ASIR, ASMR, and ASDR from 1990 to 2019 (Supplementary Tables 3, 4, and 5). Among NTDs, the highest ASIR, ASMR, and ASDR in 1990 were dengue, leishmaniasis, and intestinal nematode infections, respectively; and the highest ASIR, ASMR, and ASDR in 2019 were for dengue. The ASIR of dengue increased by 24.75%, ASMR decreased by 4%, and ASDR decreased by 17.98% in 2019, compared with 1990. In addition, this study also found that the changes in ASIR, ASMR, and ASDR of most diseases showed a downward trend in each decade. Among them, the ASMR of leishmaniasis decreased most obviously from 1990 to 1999 [AAPC: −18.56 (95% CI: −20.26 to −16.82)].

**Figure 3.** Subgroup analysis of ASIR, ASMR, and ASDR of malaria and NTDs for the SDI region from 1990 to 2019.




**A:** disease burden of malaria and NTDs among men in SDI regions from 1990 to 2019; **B:** disease burden of malaria and NTDs among women in SDI region from 1990 to 2019. ASIR: age-standardized incidence rate; ASMR: age-standardized mortality rate; ASDR: age-standardized disability-adjusted life years rate; NTDs: neglected tropical diseases; SDI: socio-demographic index.

**Figure 4.** Correlation of SDI with ASIR, ASMR, ASDR, and their AAPC.




The size of the points represents the number of cases, and the black curves are fit lines. SDI: socio-demographic index; ASIR: age-standardized incidence rate; ASMR: age-standardized mortality rate; ASDR: age-standardized disability-adjusted life years rate; AAPC: average annual percentage change.

However, the burden of a small number of diseases had increased slightly. For example, the AAPC of the ASMR for African trypanosomiasis was 2.26 (95% CI: 1.55 to 2.98) from 1990 to 1999, and the AAPC of the ASMR for dengue was 2.00 (95% CI: 1.91 to 2.10) from 2000 to 2009.

*Correlation analysis of AAPC and ASR with SDI*

The ASIR ($r = -0.79$, $p < 0.001$), ASMR ($r = -0.85$, $p < 0.001$), and ASDR ($r = -0.88$, $p < 0.001$) of malaria and NTDs had strong negative correlations with SDI in 2019 (Figure 4). However, the AAPC of ASIR ($r = 0.35$, $p < 0.001$) and ASDR ($r = 0.38$, $p < 0.001$) had positive correlations with SDI. In addition, there was no correlation between AAPC and SDI for ASMR ($r = 0.12$, $p = 0.09$).

*Predictions of the burden of malaria and NTDs from 2020 to 2030*

The predictions from 2020 to 2030 showed that the trends of global ASIR and ASDR for malaria and NTDs changed little; however, the change of ASMR (growth rate: 11.68%) showed a slowly increasing trend (Figure 5). It is worth noting that the ASMR (growth rate: – 53.28%) in the low SDI region and the ASDR (growth rate: – 44.89%) in the low-middle SDI region had a more pronounced downward trend. Predictions for males and females showed similar trends. Among them, the ASMR of males (growth rate: 11.23%) and females (growth rate: 11.96%) showed slow upward trends from 2020 to 2030 (Supplementary Figure 9). ASIR in the World Bank high-income region (growth rate: 13.14%) and World Bank upper middle-income region (growth rate: 9.22%) showed slow upward trends (Supplementary Figure 10). The largest decreases of ASMR (growth rate: – 61.38%) and ASDR (growth rate: – 44.10%) were observed in the population aged 5–14 years (Supplementary Figure 11).

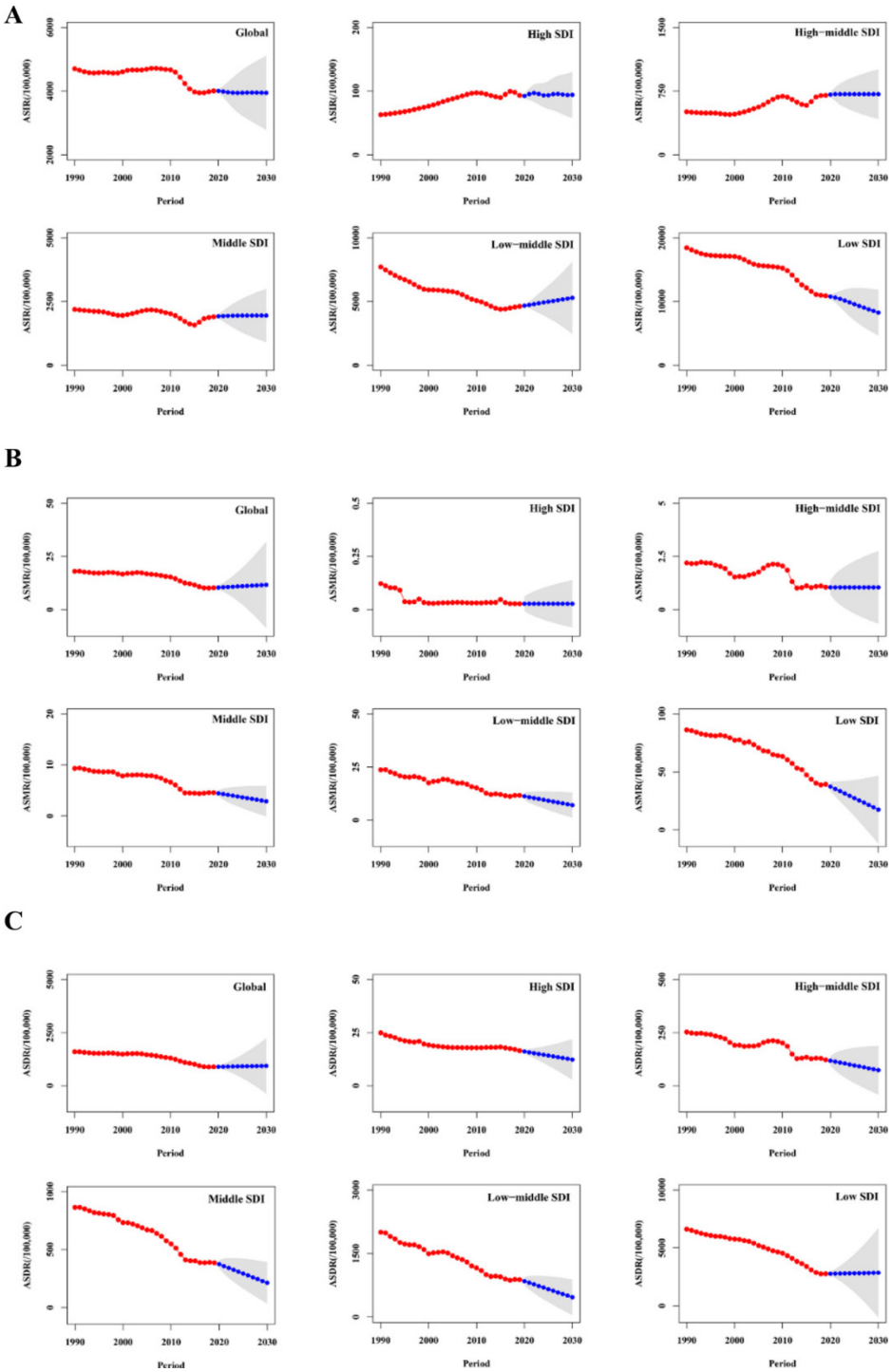
## Discussion

Globally, the ASIR of malaria and NTDs showed a decreasing trend from 1990 to 2019. Although the global ASIR of NTDs was increasing during this period, the global ASIR of malaria has declined greatly due to the widespread use of insecticide-treated mosquito nets and ATC, which eventually led to the decline of global ASIR of malaria and NTDs [25,26]. In this study, the trends of ASR were similar for males and females, and ASIR was significantly higher in females than in males. Previous studies have found an association between the incidence of NTDs and female household headship, family conditions, socioeconomic status, etc. [28]. Females are often at a disadvantage with regards to being infected with tropical diseases due to various factors such as gender inequality, poor living conditions, and lack of health awareness [29]. In addition, this study found that the ASMR and ASDR of malaria and NTDs were slightly higher in males than in females, which may be because certain NTDs are more harmful to males. For example, lymphatic filariasis is a disabling and disfiguring chronic tropical disease, that can block lymph and lead to swelling of lower limbs and genitals. The disease often affects men who hunt or fish at night, and the male scrotum becomes swollen after being infected with lymphatic filariasis [30,31].

In this study, the highest burden of malaria and NTDs worldwide was among children under 5 years of age, which is consistent with the findings of most previous studies [32–34]. Fortunately, the ASIR, ASMR, and ASDR of malaria and NTDs for children under 5 years of age showed a more significant downward trend from 1990 to 2019. As a susceptible population of malaria and NTDs, children are usually infected with various complications and sequelae [35,36]. Safe drinking water, adequate nutritional supplementation, and large-scale drug administration can reduce the risk of malaria and NTDs for children while contributing to the improvement of children's conditions and a greater reduction in the mortality and disease burden [37]. Therefore, it is very important to continuously promote awareness on malaria and NTDs and improve environmental and personal hygiene measures. In the future, the health of children under 5 years of age should be given more attention for the global control and prevention of malaria and NTDs. Active sanitation improvement and health resource assistance will be important mitigation measures in areas with a high prevalence of malaria and NTDs [38,39].

Several studies have shown that malaria and NTDs are strongly associated with poverty, which is consistent with the findings of this study [40,41]. It is worth noting that the ASIR of malaria and NTDs in high SDI and World Bank high-income regions was rising from 1990 to 2019. At the same time, relevant studies have confirmed that imported cases of malaria and NTDs have increased in most developed countries because of military operations and large influxes of migrant tourists from endemic areas, ultimately causing a large number of deaths and severe disease burden [42–44]. Climate change, world trade, population movements, and decreasing vaccination rates have led to a significant increase in the number of cases in developed countries [45,46].

**Figure 5.** Predictions of malaria and NTDs in different SDI regions from 2020 to 2030.




**A:** ASIR of malaria and NTDs in different SDI regions from 2020 to 2030; **B:** ASMR of malaria and NTDs in different SDI regions from 2020 to 2030; **C:** ASDR of malaria and NTDs in different SDI regions from 2020 to 2030. The red dots represent the corresponding rates from 1990 to 2019; the blue dots represent the predictions from 2020 to 2030; and the shading represents the 95% confidence intervals. ASIR: age-standardized incidence rate; ASMR: age-standardized mortality rate; ASDR: age-standardized disability-adjusted life years rate; SDI: socio-demographic index; NTDs: neglected tropical diseases.

Therefore, future prevention and treatment of malaria and NTDs can no longer be limited to low-income regions and developing countries. Furthermore, the ASIR of malaria and NTDs in western sub-Saharan Africa had increased significantly from 1990 to 2019. In particular, Benin was the country with the highest ASIR of malaria and NTDs in 2019. The ASIR of malaria has increased significantly due to rising mosquito vector resistance in countries such as Benin and Gambia [47,48]. Therefore, there is need to intensify research and development of medicines, expand vaccination against malaria and NTDs in all regions, and improve the accessibility of medical resources.

## Conclusions

This study observed that the highest disease burden of the NTDs was dengue in 2019 and the ASIR of dengue steadily increased from 1990 to 2019. Relevant studies have found that dengue has transformed from a sporadic disease to a worldwide epidemic with high mortality and severe disease burden [49,50]. Although the control measures against dengue are being strengthened; the incidence, mortality, and disease burden of dengue have been increasing continuously. The primary reasons for the rising incidence of dengue may be the diversification of infectious pathways, transnational population movements, and the existence of various dengue sera [51,52]. In 2021, WHO developed a plan for managing NTDs in the period 2021–2030, which proposed new goals, approaches, and interventions; and aimed to eliminate the harm to human health caused by global NTDs [53]. The predicted results showed that the global ASMR of malaria and NTDs in the World Bank high-income region will continue to rise from 2020 to 2030. In order to end the harm caused by malaria and NTDs to human health, there is urgent need to improve the diagnosis and treatment of these tropical diseases, strengthen the research and development of new pesticides and effective vaccines, and work together with the government, communities and international organizations to prevent and control the increase of malaria and NTDs. At the same time, the World Bank high-income region and the World Bank upper middle-income region should be alerted to increased morbidity due to factors such as population migration, urbanization, and climate change.

This research has several limitations. Firstly, this study combined the disease burden of malaria and NTDs based on the GBD database, but it could not determine the number of people suffering from co-infection with both diseases and their disease burden, which may not be conducive to accurate control and prevention of malaria and NTDs, and it deserves further study. Second, the GBD database collected data on different types of NTDs, but data are missing for some regions or diseases with low incidence; therefore, this may lead to an underestimation of the global disease burden for both malaria and NTDs, as well as some bias in the results comparing the burden of different NTDs. Third, the study predicted the future disease burden of malaria and NTDs, which is informative for the future control of epidemics of the two diseases. However, changes in climate, treatment modalities, and vaccine policies in the future may result in the disease burden of malaria and NTDs following a different trend, thereby reducing the long-term accuracy of the predictions in this study; therefore, further research based on new data will be needed in the future.

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### Authors' contributions

DL, SZ, conception and study design; DL, YS, data analysis, results summary, manuscript completion; RW, RH, visualization; TS, SZ, manuscript review and edit. All authors read and approved the manuscript.

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### Conflict of interest

No conflict of interest is declared.

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# Annex – Supplementary Items

**Supplementary Table 1.** Mortality cases, ASMR and AAPC of malaria and NTDs worldwide from 1990 to 2019.

| Characteristics | 1990 | | 2019 | | AAPC of ASIR (95% CI) |
|---|---|---|---|---|---|
| | Mortality cases (95% UI) | ASMR/100,000 (95% UI) | Mortality cases (95% UI) | ASMR/100, 000 (95% UI) | |
| Total | 1034118.59 (638521.28, 1551483.96) | 18.06 (11.26, 27.02) | 747343.72 (406562.08, 1247137.81) | 10.32 (5.61, 17.27) | -1.91 (-2.39, -1.43) |
| Male | 534845.38 (334860.22, 817074.13) | 18.74 (11.84, 28.47) | 394035.14 (217155.15, 652725.06) | 10.73 (5.92, 17.77) | -1.88 (-2.32, -1.45) |
| Female | 499273.21 (306658.79, 759080.36) | 17.52 (10.82, 26.48) | 353308.57 (189698.33, 590879.83) | 9.94 (5.32, 16.65) | -1.94 (-2.41, -1.47) |
| **SDI Region** | | | | | |
| High-middle SDI | 23561.16 (14524.70, 42339.76) | 2.20 (1.37, 3.92) | 14733.77 (10438.10, 20246.68) | 1.06 (0.74, 1.45) | -2.41 (-3.74, -1.06) |
| High SDI | 1114.44 (946.76, 1833.82) | 0.12 (0.10, 0.23) | 438.33 (205.88, 527.64) | 0.03 (0.01, 0.03) | -4.87 (-6.82, -2.88) |
| Low-middle SDI | 286954.70 (171462.54, 485219.82) | 23.68 (14.31, 38.76) | 188040.74 (103632.16, 303470.70) | 11.63 (6.47, 18.63) | -2.49 (-3.06, -1.92) |
| Low SDI | 566763.99 (319129.67, 911332.75) | 86.19 (49.89, 137.65) | 442274.21 (214458.22, 781598.75) | 39.26 (19.00, 69.61) | -2.71 (-3.28, -2.13) |
| Middle SDI | 155385.98 (102732.18, 227345.74) | 9.31 (6.29, 13.4) | 101636.73 (66941.75, 150541.17) | 4.56 (3.03, 6.68) | -2.45 (-3.20, -1.69) |
| **GBD Region** | | | | | |
| Andean Latin America | 2408.44 (1234.64, 4410.56) | 7.38 (3.88, 13.09) | 820.50 (364.70, 1522.70) | 1.46 (0.64, 2.74) | -5.67 (-7.58, -3.73) |
| Australasia | 2.99 (2.05, 4.17) | 0.01 (0.01, 0.02) | 2.60 (1.80, 3.40) | 0.01 (0.00, 0.01) | -3.52 (-6.16, -0.82) |
| Caribbean | 862.53 (438.05, 1578.54) | 2.51 (1.33, 4.55) | 647.60 (221.20, 1773.90) | 1.37 (0.47, 3.74) | -3.97 (-9.24, 1.61) |
| Central Asia | 713.33 (168.96, 2013.59) | 0.86 (0.27, 2.26) | 134.20 (73.80, 401.10) | 0.17 (0.10, 0.46) | -5.90 (-6.77, -5.02) |
| Central Europe | 271.39 (126.57, 1283.69) | 0.25 (0.11, 1.16) | 45.20 (28.50, 79.50) | 0.03 (0.02, 0.07) | -7.41 (-8.42, -6.39) |
| Central Latin America | 3843.77 (2274.69, 5565.44) | 3.05 (1.78, 4.17) | 3360.30 (2270.00, 5026.10) | 1.42 (0.97, 2.11) | -3.27 (-4.04, -2.49) |
| Central Sub-Saharan Africa | 109981.63 (61218.69, 171335.17) | 137.96 (82.12, 209.04) | 82920.00 (41474.60, 137565.10) | 59.41 (30.33, 100.56) | -2.90 (-3.45, -2.34) |
| East Asia | 6725.65 (4399.49, 23555.10) | 0.65 (0.45, 2.03) | 1914.00 (1327.40, 2282.00) | 0.11 (0.07, 0.13) | -6.15 (-7.37, -4.91) |
| Eastern Europe | 215.23 (147.35, 268.81) | 0.10 (0.07, 0.12) | 142.40 (91.70, 176.00) | 0.06 (0.04, 0.08) | -1.57 (-2.21, -0.93) |
| Eastern Sub-Saharan Africa | 245208.16 (139278.03, 387644.08) | 105.77 (62.57, 167.23) | 129573.60 (59485.30, 236781.20) | 31.9 (14.65, 59.83) | -3.98 (-4.58, -3.36) |
| High-income Asia Pacific | 47.39 (37.23, 54.37) | 0.03 (0.02, 0.03) | 99.20 (31.90, 135.80) | 0.02 (0.01, 0.03) | -0.68 (-1.06, -0.30) |
| High-income North America | 58.08 (43.3, 122.69) | 0.02 (0.01, 0.04) | 200.10 (73.90, 238.10) | 0.04 (0.01, 0.05) | 2.59 (1.04, 4.17) |
| North Africa and Middle East | 19048.62 (8832.70, 45215.55) | 6.04 (2.97, 12.39) | 10088.90 (3577.00, 23463.40) | 1.78 (0.66, 4.08) | -4.22 (-4.83, -3.61) |
| Oceania | 1008.83 (350.04, 2490.07) | 18.69 (6.72, 44.99) | 1192.30 (324.90, 3232.70) | 10.61 (2.93, 28.89) | -1.83 (-4.14, 0.54) |
| South Asia | 264240.96 (142518.19, 495146.20) | 21.85 (11.74, 41.96) | 70398.10 (42599.80, 126270.00) | 4.42 (2.67, 7.74) | -5.74 (-6.56, -4.92) |
| Southeast Asia | 37186.30 (17911.26, 59866.11) | 7.65 (4.06, 12.92) | 16710.20 (7393.10, 21255.20) | 2.75 (1.19, 3.52) | -3.29 (-4.07, -2.50) |
| Southern Latin America | 1287.21 (692.07, 2293.56) | 2.97 (1.61, 5.42) | 939.00 (520.10, 2874.70) | 1.14 (0.64, 3.45) | -3.23 (-3.45, -3.02) |
| Southern Sub-Saharan Africa | 4934.26 (1798.84, 10637.36) | 8.89 (3.38, 18.82) | 3131.90 (809.80, 9332.70) | 4.06 (1.13, 12.01) | -2.79 (-4.13, -1.44) |
| Tropical Latin America | 14457.69 (7520.38, 20102.25) | 12.91 (6.46, 17.15) | 9219.00 (5040.00, 13736.80) | 3.96 (2.13, 5.96) | -4.08 (-4.26, -3.90) |
| Western Europe | 929.99 (815.04, 1333.25) | 0.18 (0.15, 0.31) | 122.00 (67.20, 236.70) | 0.02 (0.01, 0.05) | -8.24 (-10.93, -5.46) |
| Western Sub-Saharan Africa | 320686.15 (169189.26, 536583.17) | 147.75 (78.71, 249.40) | 415682.50 (206252.90, 736045.90) | 109.51 (53.05, 201.10) | -1.03 (-1.54, -0.51) |

AAPC: average annual percentage change; ASMR: age-standardized mortality rate; NTDs: neglected tropical diseases.

**Supplementary Table 2.** DALYs, ASDR, and AAPC of malaria and NTDs worldwide from 1990 to 2019.

| Characteristics | 1990 | | 2019 | | AAPC of ASIR (95% CI) |
|---|---|---|---|---|---|
| | DALYs (95%UI) | ASDR/100,000 (95% UI) | DALYs (95% UI) | ASDR/100,000 (95% UI) | |
| Total | 94425891.58 (63899893.01, 134921004.20) | 1596.63 (1099.29, 2263.78) | 62903804.67 (38609885.53, 95989237.10) | 884.96 (537.27, 1356.63) | -2.04 (-2.32, -1.76) |
| Male | 48903021.40 (33619165.04, 69744707.14) | 1638.96 (1142.09, 2319.02) | 32462044.54 (19823859.62, 49837508.17) | 892.16 (544.05, 1373.61) | -2.10 (-2.37, -1.83) |
| Female | 45522870.18 (30179557.12, 65989656.89) | 1558.82 (1046.62, 2244.41) | 30441760.13 (18720869.48, 46305720.70) | 879.22 (534.37, 1342.14) | -1.98 (-2.27, -1.70) |
| High-middle SDI | 2813926.30 (1975972.41, 4158089.96) | 252.52 (175.77, 376.74) | 1632064.47 (1225664.25, 2120206.42) | 121.96 (91.80, 155.99) | -2.36 (-3.05, -1.66) |
| High SDI | 211584.27 (154387.08, 277718.58) | 24.88 (18.07, 33.60) | 208706.93 (149604.63, 282686.54) | 16.47 (12.00, 22.22) | -1.39 (-1.63, -1.15) |
| Low-middle SDI | 26516310.08 (17764567.28, 41458294.82) | 2000.99 (1377.79, 3006.25) | 15179995.54 (9518155.55, 22174386.82) | 879.86 (551.73, 1286.23) | -2.86 (-3.24, -2.48) |
| Low SDI | 49271637.99 (29903424.18, 75125236.53) | 6610.94 (4281.28, 9756.57) | 37402634.85 (20974987.71, 61102872.24) | 2767.10 (1602.60, 4446.44) | -2.99 (-3.23, -2.75) |
| Middle SDI | 15577939.63 (11357912.25, 20853719.38) | 863.50 (643.01, 1140.10) | 8457692.13 (6184827.49, 11004301.13) | 385.56 (280.56, 507.13) | -2.79 (-3.21, -2.37) |
| Andean Latin America | 241195.81 (155822.40, 371526.27) | 651.12 (443.06, 969.85) | 120199.32 (82769.47, 166047.61) | 196.17 (134.82, 271.03) | -4.19 (-5.61, -2.75) |
| Australasia | 1735.12 (967.91, 2960.31) | 9.52 (5.36, 16.26) | 1644.89 (801.45, 3046.84) | 6.62 (3.27, 11.83) | -1.26 (-1.34, -1.17) |
| Caribbean | 141264.53 (98095.08, 192664.82) | 396.09 (279.03, 535.51) | 100542.43 (64344.68, 165589.93) | 215.05 (137.47, 355.78) | -2.76 (-6.07, 0.67) |
| Central Asia | 126085.87 (69632.14, 231740.96) | 164.11 (98.36, 272.99) | 71834.95 (47817.81, 103336.45) | 77.78 (52.30, 111.05) | -3.06 (-3.73, -2.40) |
| Central Europe | 68060.77 (43523.52, 135193.90) | 53.51 (33.93, 117.58) | 52544.10 (33419.10, 76653.22) | 33.42 (22.30, 46.89) | -1.60 (-1.71, -1.49) |
| Central Latin America | 500745.20 (374959.08, 654077.45) | 323.23 (249.32, 409.73) | 430030.32 (326680.53, 543402.42) | 175.31 (133.78, 220.70) | -2.49 (-2.90, -2.08) |
| Central Sub-Saharan Africa | 9882246.92 (5854608.75, 14816993.26) | 11677.82 (7687.42, 16870.95) | 7561214.43 (4363266.75, 11559274.04) | 4763.25 (2871.02, 7168.40) | -3.01 (-3.24, -2.77) |
| East Asia | 2603986.11 (1622646.39, 4070894.32) | 218.82 (138.27, 335.40) | 1161098.85 (708126.37, 1836690.97) | 67.47 (41.87, 105.04) | -3.97 (-4.26, -3.68) |
| Eastern Europe | 117183.67 (81956.23, 157449.25) | 46.74 (33.57, 62.34) | 96587.75 (66168.67, 132245.32) | 34.54 (24.23, 46.64) | -1.04 (-1.10, -0.98) |
| Eastern Sub-Saharan Africa | 20842087.13 (12573118.74, 31845293.12) | 7587.79 (4885.43, 11218.65) | 11406000.30 (6177271.60, 18923070.46) | 2302.84 (1298.87, 3841.00) | -4.03 (-4.45, -3.60) |
| High-income Asia Pacific | 49879.01 (34801.68, 68645.53) | 29.07 (20.08, 40.54) | 45001.75 (30981.51, 62509.10) | 20.04 (13.78, 28.11) | -1.27 (-1.37, -1.17) |
| High-income North America | 72705.52 (47200.25, 104792.80) | 22.46 (14.86, 32.26) | 100977.14 (64268.93, 149894.47) | 19.70 (13.10, 28.31) | -0.43 (-0.63, -0.24) |
| North Africa and Middle East | 1794192.17 (1057379.08, 3677359.98) | 502.88 (312.12, 926.79) | 1136429.46 (676501.02, 1827124.33) | 185.48 (111.65, 297.24) | -3.60 (-4.04, -3.17) |
| Oceania | 113251.05 (69250.24, 204749.96) | 1802.03 (1112.25, 3137.16) | 131514.66 (76585.93, 240096.19) | 1009.00 (585.56, 1857.48) | -2.34 (-4.09, -0.56) |
| South Asia | 25328875.31 (15778277.39, 43116953.25) | 1973.98 (1259.90, 3271.61) | 7274290.24 (5088917.47, 10500096.37) | 417.61 (293.86, 601.09) | -5.41 (-5.65, -5.17) |
| Southeast Asia | 4584996.31 (2940385.89, 6302719.68) | 921.67 (624.84, 1250.43) | 1802287.97 (1162003.29, 2292388.51) | 283.55 (179.58, 359.62) | -3.91 (-4.45, -3.36) |
| Southern Latin America | 85498.10 (62699.07, 119847.36) | 178.84 (130.94, 247.91) | 54563.96 (37949.56, 94208.20) | 73.38 (51.13, 122.65) | -3.04 (-3.12, -2.96) |
| Southern Sub-Saharan Africa | 586141.17 (334050.25, 984460.74) | 1008.50 (604.77, 1659.61) | 359292.27 (181026.15, 745203.13) | 458.42 (240.86, 940.71) | -2.70 (-3.52, -1.88) |
| Tropical Latin America | 906894.15 (576784.11, 1248377.98) | 661.86 (415.36, 883.21) | 538434.84 (378498.43, 766476.29) | 235.86 (162.63, 349.52) | -3.54 (-3.72, -3.35) |
| Western Europe | 44778.64 (31220.34, 70519.25) | 11.38 (7.62, 20.17) | 33828.41 (22132.76, 49365.79) | 6.60 (4.39, 9.74) | -1.87 (-2.15, -1.59) |
| Western Sub-Saharan Africa | 26334089.01 (14964045.59, 42713459.16) | 9957.95 (6039.74, 15650.92) | 30425486.66 (16381998.79, 51117804.35) | 5873.21 (3147.39, 9999.82) | -1.80 (-2.09, -1.50) |

AAPC: average annual percentage change; ASDR: age-standardized disability-adjusted life years rate; NTDs: neglected tropical diseases.

**Supplementary Table 3.** Changes in ASIR for malaria and different types of NTDs from 1990 to 2019.

| Diseases | 1990 | 2019 | 1990–2019 | | 1990–1999 | | 2000–2009 | | 2010–2019 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ASIR/100000(95% UI) | ASIR/100000(95% UI) | AAPC (95% CI) | p value | AAPC (95% CI) | p value | AAPC (95% CI) | p value | AAPC (95% CI) | p value |
| African trypanosomiasis | 0.69 (0.47, 1.04) | 0.03 (0.02, 0.04) | -10.85 (-11.54, -10.17) | < 0.001 | 2.26 (1.55, 2.98) | < 0.001 | -14.00 (-15.40, -12.57) | < 0.001 | -20.32 (-21.86, -18.75) | < 0.001 |
| Chagas disease | 4.07 (3.54, 4.68) | 2.27 (2.00, 2.56) | -2.00 (-2.13, -1.88) | < 0.001 | -3.12 (-3.19, -3.05) | < 0.001 | -1.45 (-1.56, -1.34) | < 0.001 | -1.82 (-2.05, -1.60) | < 0.001 |
| Cystic echinococcosis | 2.65 (1.87, 3.70) | 2.60 (1.72, 3.79) | -0.07 (-0.09, -0.06) | < 0.001 | 0.02 (-0.04, 0.07) | 0.550 | -0.40 (-0.45, -0.34) | < 0.001 | 0.16 (0.15, 0.17) | < 0.001 |
| Dengue | 557.15 (243.32, 1212.53) | 740.38 (478.25, 1323.07) | 1.01 (0.94, 1.07) | < 0.001 | 1.36 (1.34, 1.37) | < 0.001 | 2.00 (1.91, 2.10) | < 0.001 | -0.42 (-0.62, -0.22) | < 0.001 |
| Guinea worm disease | 30.83 (30.35, 31.34) | 0.00 (0.00, 0.00) | -32.99 (-35.66, -30.21) | < 0.001 | -31.52 (-34.94, -27.91) | < 0.001 | -33.55 (-37.25, -29.63) | < 0.001 | -42.08 (-49.07, -34.13) | < 0.001 |
| Leishmaniasis | 17.15 (14.05, 20.77) | 8.70 (6.54, 11.42) | -2.31 (-2.57, -2.05) | < 0.001 | -4.70 (-4.80, -4.60) | < 0.001 | 1.54 (1.40, 1.69) | < 0.001 | -4.75 (-5.40, -4.10) | < 0.001 |
| Leprosy | 1.48 (1.30, 1.73) | 0.65 (0.57, 0.75) | -2.79 (-2.85, -2.73) | < 0.001 | -4.23 (-4.29, -4.16) | < 0.001 | -2.89 (-3.08, -2.71) | < 0.001 | -1.51 (-1.57, -1.44) | < 0.001 |
| Malaria | 4084.09 (3388.02, 4998.95) | 3247.02 (2602.06, 4109.56) | -0.80 (-0.95, -0.64) | < 0.001 | -0.43 (-0.59, -0.26) | < 0.001 | -0.18 (-0.44, 0.08) | 0.182 | -2.17 (-2.77, -1.57) | < 0.001 |
| Rabies | 0.46 (0.18, 0.75) | 0.18 (0.08, 0.28) | -3.08 (-3.25, -2.91) | < 0.001 | -1.93 (-2.07, -1.78) | < 0.001 | -3.96 (-4.14, -3.78) | < 0.001 | -3.41 (-3.52, -3.30) | < 0.001 |
| Yellow fever | 4.64 (1.78, 10.02) | 1.50 (0.57, 3.30) | -3.85 (-4.15, -3.55) | < 0.001 | -3.91 (-4.23, -3.60) | < 0.001 | -3.82 (-4.25, -3.40) | < 0.001 | -4.57 (-5.88, -3.25) | < 0.001 |

ASIR: age-standardized incidence rate; AAPC: average annual percentage change; NTDs: neglected tropical diseases.

**Supplementary Table 4.** Changes in ASMR for malaria and different types of NTDs from 1990 to 2019.

| | ASMR/100000 (95% UI) | ASMR/100000 (95% UI) | AAPC (95% CI) | p value | AAPC (95% CI) | p value | AAPC (95% CI) | p value | AAPC (95% CI) | p value |
|---|---|---|---|---|---|---|---|---|---|---|
| African trypanosomiasis | 0.32 (0.16, 0.53) | 0.02 (0.01, 0.03) | -9.67 (-10.94, -8.39) | < 0.001 | 3.35 (-1.34, 8.26) | 0.164 | -13.47 (-15.44, -11.45) | < 0.001 | -17.59 (-20.52, -14.55) | < 0.001 |
| Chagas disease | 0.31 (0.14, 0.37) | 0.12 (0.07, 0.21) | -3.32 (-3.62, -3.02) | < 0.001 | -5.23 (-5.92, -4.54) | < 0.001 | -2.76 (-2.92, -2.59) | < 0.001 | -2.01 (-2.32, -1.69) | < 0.001 |
| Cystic echinococcosis | 0.06 (0.04, 0.07) | 0.02 (0.01, 0.02) | -3.86 (-4.04, -3.68) | < 0.001 | -3.78 (-3.91, -3.65) | < 0.001 | -5.13 (-5.25, -5.00) | < 0.001 | -2.04 (-2.36, -1.71) | < 0.001 |
| Cysticercosis | 0.03 (0.02, 0.04) | 0.01 (0.01, 0.02) | -2.40 (-2.50, -2.34) | < 0.001 | -1.81 (-2.00, -1.61) | < 0.001 | -2.94 (-3.04, -2.84) | < 0.001 | -2.43 (-2.57, -2.30) | < 0.001 |
| Dengue | 0.50 (0.12, 0.74) | 0.48 (0.12, 0.59) | -0.09 (-0.39, 0.22) | 0.574 | -0.96 (-1.74, -0.18) | 0.023 | 0.41 (-0.12, 0.93) | 0.130 | -0.11 (-0.59, 0.38) | 0.629 |
| Intestinal nematode infections | 0.13 (0.10, 0.17) | 0.03 (0.02, 0.04) | -4.88 (-5.08, -4.67) | < 0.001 | -3.68 (-3.74, -3.62) | < 0.001 | -3.95 (-4.51, -3.39) | < 0.001 | -6.58 (-7.04, -6.11) | < 0.001 |
| Leishmaniasis | 1.00 (0.33, 3.28) | 0.08 (0.02, 0.26) | -8.49 (-9.73, -7.22) | < 0.001 | -18.56 (-20.26, -16.82) | < 0.001 | 1.45 (-0.69, 3.63) | 0.187 | -9.68 (-10.60, -8.75) | < 0.001 |
| Malaria | 14.42 (7.96, 23.21) | 8.95 (4.23, 16.00) | -1.65 (-2.02, -1.27) | < 0.001 | 0.26 (0.00, 0.51) | 0.049 | -0.34 (-0.73, 0.05) | 0.086 | -4.53 (-5.57, -3.48) | < 0.001 |
| Other neglected tropical diseases | 0.20 (0.13, 0.47) | 0.19 (0.13, 0.48) | -0.20 (-0.40, -0.07) | 0.004 | -0.75 (-0.93, -0.57) | < 0.001 | 0.35 (0.25, 0.45) | < 0.001 | -0.11 (-0.37, 0.15) | 0.356 |
| Rabies | 0.48 (0.74, 0.18) | 0.18 (0.08, 0.24) | -3.38 (-3.69, -3.06) | < 0.001 | -2.19 (-2.37, -2.01) | < 0.001 | -3.58 (-4.30, -2.84) | < 0.001 | -3.80 (-4.01, -3.59) | < 0.001 |
| Schistosomiasis | 0.40 (0.35, 0.44) | 0.14 (0.12, 0.16) | -3.47 (-3.65, -3.30) | < 0.001 | -2.22 (-2.49, -1.94) | < 0.001 | -4.77 (-5.10, -4.45) | < 0.001 | -3.34 (-4.02, -2.67) | < 0.001 |
| Yellow fever | 0.23 (0.09, 0.48) | 0.06 (0.02, 0.12) | -4.51 (-6.22, -2.77) | < 0.001 | -4.92 (-10.41, 0.90) | 0.096 | -5.00 (-6.02, -3.97) | < 0.001 | -5.36 (-7.83, -2.83) | 0.001 |

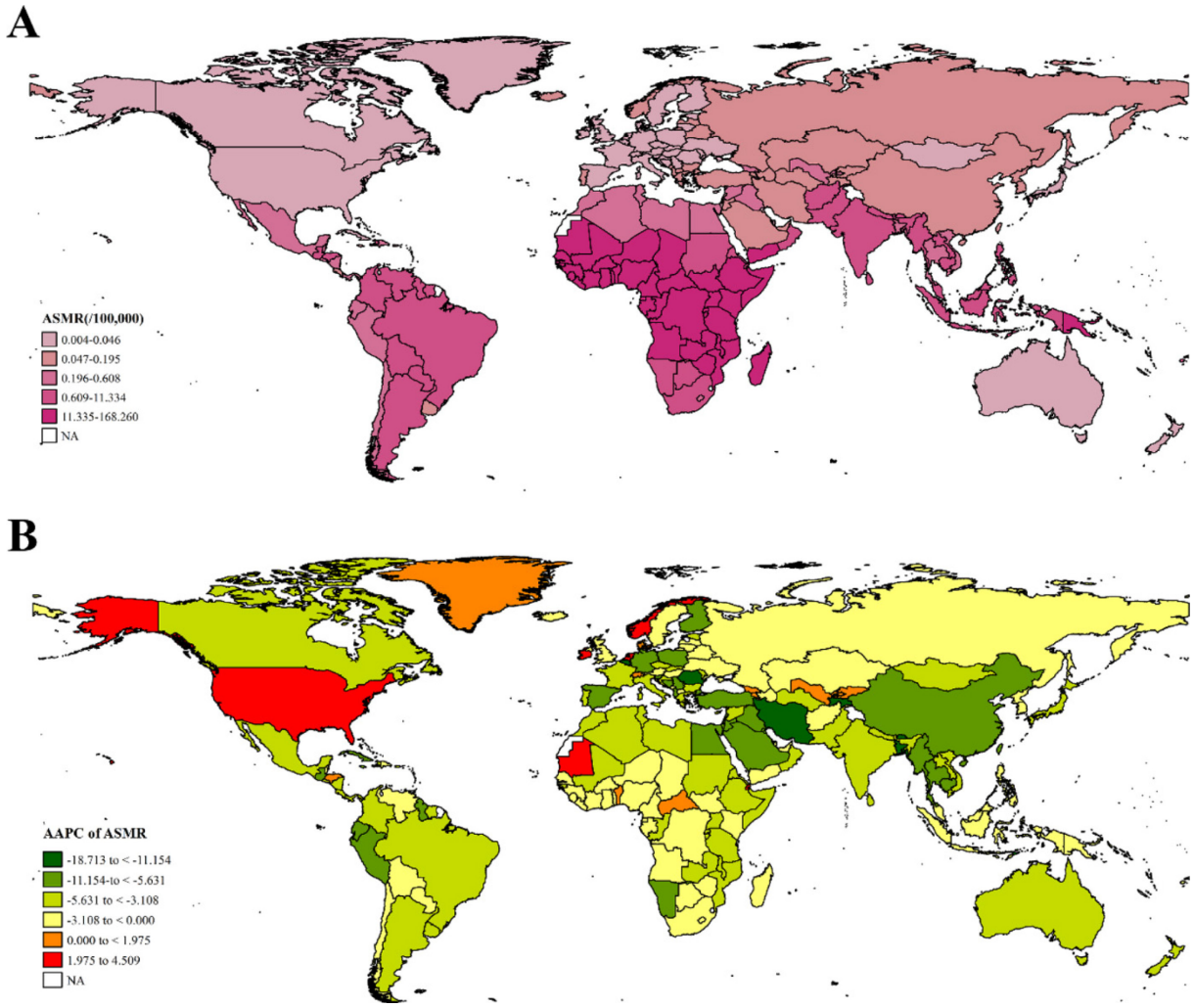
ASMR: age-standardized mortality rate; AAPC: average annual percentage change; NTDs: neglected tropical diseases; SDI: socio-demographic index.

**Supplementary Table 5.** Changes in ASDR for malaria and different types of NTDs from 1990 to 2019.

| Diseases | 1990 | 2019 | 1990–2019 | | 1990–1999 | | 2000–2009 | | 2010–2019 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ASDR/100, 000 (95% UI) | ASDR/100, 000 (95% UI) | AAPC (95% CI) | *p* value | AAPC (95% CI) | *p* value | AAPC (95% CI) | *p* value | AAPC (95% CI) | *p* value |
| African trypanosomiasis | 18.13 (8.83, 29.44) | 1s.10 (0.49, 2.10) | -9.41 (-10.66, -8.14) | < 0.001 | 3.50 (-0.89, 8.08) | 0.119 | -13.11 (-15.04, -11.14) | < 0.001 | -17.33 (-20.23, -14.33) | < 0.001 |
| Chagas disease | 8.51 (3.72, 10.53) | 3.34 (2.25, 5.57) | -3.19 (-3.33, -3.05) | < 0.001 | -4.43 (-4.63, -4.24) | < 0.001 | -3.08 (-3.28, -2.87) | < 0.001 | -1.86 (-2.28, -1.43) | < 0.001 |
| Cystic echinococcosis | 3.82 (3.05, 4.70) | 1.56 (1.14, 2.16) | -2.98 (-3.11, -2.86) | < 0.001 | -3.13 (-3.21, -3.06) | < 0.001 | -3.70 (-3.82, -3.58) | < 0.001 | -1.72 (-1.95, -1.49) | < 0.001 |
| Cysticercosis | 23.77 (15.05, 34.04) | 16.79 (10.74, 23.88) | -1.20 (-1.24, -1.15) | < 0.001 | -0.77 (-0.89, -0.65) | < 0.001 | -1.49 (-1.52, -1.45) | < 0.001 | -1.34 (-1.42, -1.26) | < 0.001 |
| Dengue | 39.21 (9.32, 61.96) | 32.16 (11.11, 44.15) | -0.62 (-0.89, -0.35) | < 0.001 | -1.21 (-1.92, -0.50) | 0.005 | 0.12 (-0.40, 0.64) | 0.660 | -1.08 (-1.46, -0.70) | < 0.001 |
| Food-borne trematodiases | 22.54 (10.00, 44.21) | 9.47 (4.67, 17.57) | -2.90 (-3.05, -2.74) | < 0.001 | -4.51 (-4.64, -4.37) | < 0.001 | -3.19 (-3.28, -3.10) | < 0.001 | -0.70 (-1.71, 0.32) | 0.180 |
| Guinea worm disease | 0.50 (0.31, 0.73) | 0.00 (0.00, 0.00) | -31.38 (-34.13, -28.51) | < 0.001 | -31.04 (-35.05, -26.77) | < 0.001 | -33.19 (-35.42, -30.89) | < 0.001 | -37.09 (-53.54, -14.80) | 0.003 |
| Intestinal nematode infections | 91.23 (58.69, 135.75) | 26.60 (17.03, 40.49) | -4.17 (-4.36, -3.98) | < 0.001 | -2.86 (-2.94, -2.78) | < 0.001 | -4.95 (-5.19, -4.71) | < 0.001 | -4.71 (-4.88, -4.53) | < 0.001 |
| Leishmaniasis | 74.14 (26.92, 236.57) | 9.39 (5.00, 22.22) | -6.95 (-7.97, -5.92) | < 0.001 | -17.07 (-18.71, -15.39) | < 0.001 | 1.35 (-0.32, 3.04) | 0.113 | -6.51 (-7.09, -5.92) | < 0.001 |
| Leprosy | 0.95 (0.62, 1.39) | 0.35 (0.23, 0.51) | -3.31 (-3.44, -3.18) | < 0.001 | -4.11 (-4.31, -3.92) | < 0.001 | -4.35 (-4.68, -4.03) | < 0.001 | -1.66 (-1.75, -1.58) | < 0.001 |
| Lymphatic filariasis | 81.23 (54.25, 117.00) | 20.71 (12.18, 34.66) | -4.79 (-5.51, -4.08) | < 0.001 | 0.05 (-0.08, 0.18) | 0.411 | -10.77 (-11.91, -9.61) | < 0.001 | -2.81 (-3.96, -1.64) | 0.001 |
| Malaria | 1074.99 (608.96, 1721.22) | 668.11 (337.28, 1152.22) | -1.64 (-2.00, -1.27) | < 0.001 | 0.28 (0.05, 0.51) | 0.023 | -0.36 (-0.67, -0.05) | 0.023 | -4.72 (-5.53, -3.90) | < 0.001 |
| Onchocerciasis | 26.24 (16.65, 38.18) | 15.69 (9.75, 23.28) | -1.75 (-1.83, -1.67) | < 0.001 | -3.49 (-3.58, -3.40) | < 0.001 | -1.97 (-2.14, -1.80) | < 0.001 | 0.22 (0.12, 0.32) | < 0.001 |
| Other neglected tropical diseases | 43.60 (30.30, 67.77) | 39.43 (27.00, 63.68) | -0.34 (-0.38, -0.31) | < 0.001 | -0.42 (-0.45, -0.39) | < 0.001 | -0.30 (-0.35, -0.25) | < 0.001 | -0.31 (-0.51, -0.12) | 0.001 |
| Rabies | 29.71 (10.80, 47.62) | 10.59 (4.38, 14.69) | -3.55 (-3.87, -3.23) | < 0.001 | -2.25(-2.52, -1.97) | < 0.001 | -3.75 (-4.63, -2.86) | < 0.001 | -4.07(-4.30, -3.83) | < 0.001 |
| Schistosomiasis | 36.30 (25.12, 54.89) | 20.92 (13.23, 33.73) | -1.90 (-1.98, -1.81) | < 0.001 | -0.57 (-0.71, -0.43) | < 0.001 | -1.51 (-1.56, -1.47) | < 0.001 | -3.69 (-4.05, -3.33) | < 0.001 |
| Trachoma | 7.28 (4.61, 10.96) | 2.20 (1.39, 3.33) | -4.04 (-4.25, -3.82) | < 0.001 | -3.24 (-3.38, -3.09) | < 0.001 | -5.96 (-6.31, -5.61) | < 0.001 | -2.89 (-3.13, -2.66) | < 0.001 |
| Yellow fever | 14.48 (5.43, 30.53) | 3.98 (1.47, 8.21) | -4.27 (-5.97, -2.54) | < 0.001 | -4.57 (-9.96, 1.14) | 0.114 | -4.66 (-5.66, -3.65) | < 0.001 | -5.52 (-7.97, -3.00) | 0.001 |

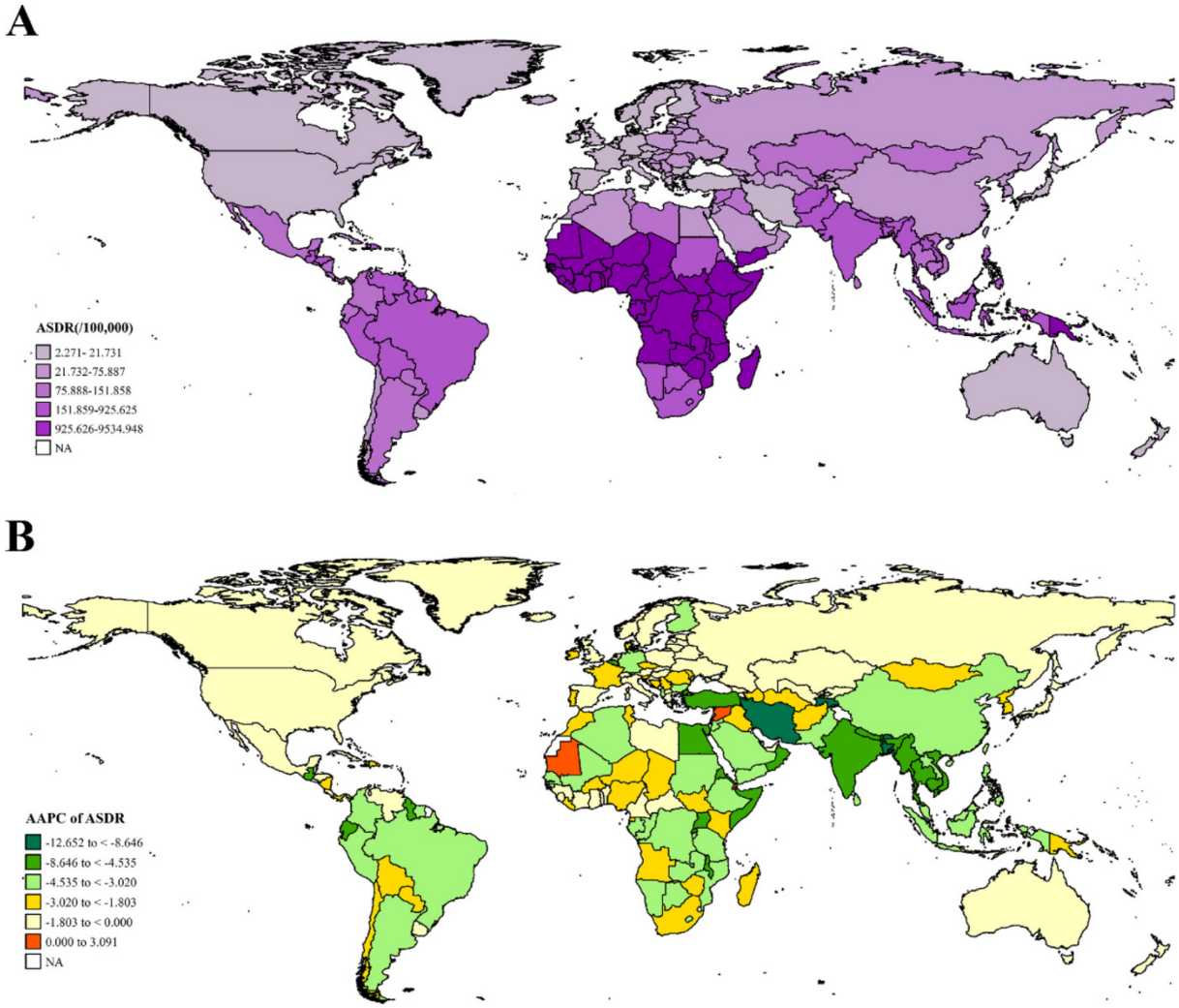
AAPC: average annual percentage change; ASDR: age-standardized disability-adjusted life years rate; GBD: global burden of disease; NTDs: neglected tropical diseases; SDI: socio-demographic index.

**Supplementary Figure 1.** ASMR for malaria and NTDs worldwide in 2019, and AAPC from 1990 to 2019.



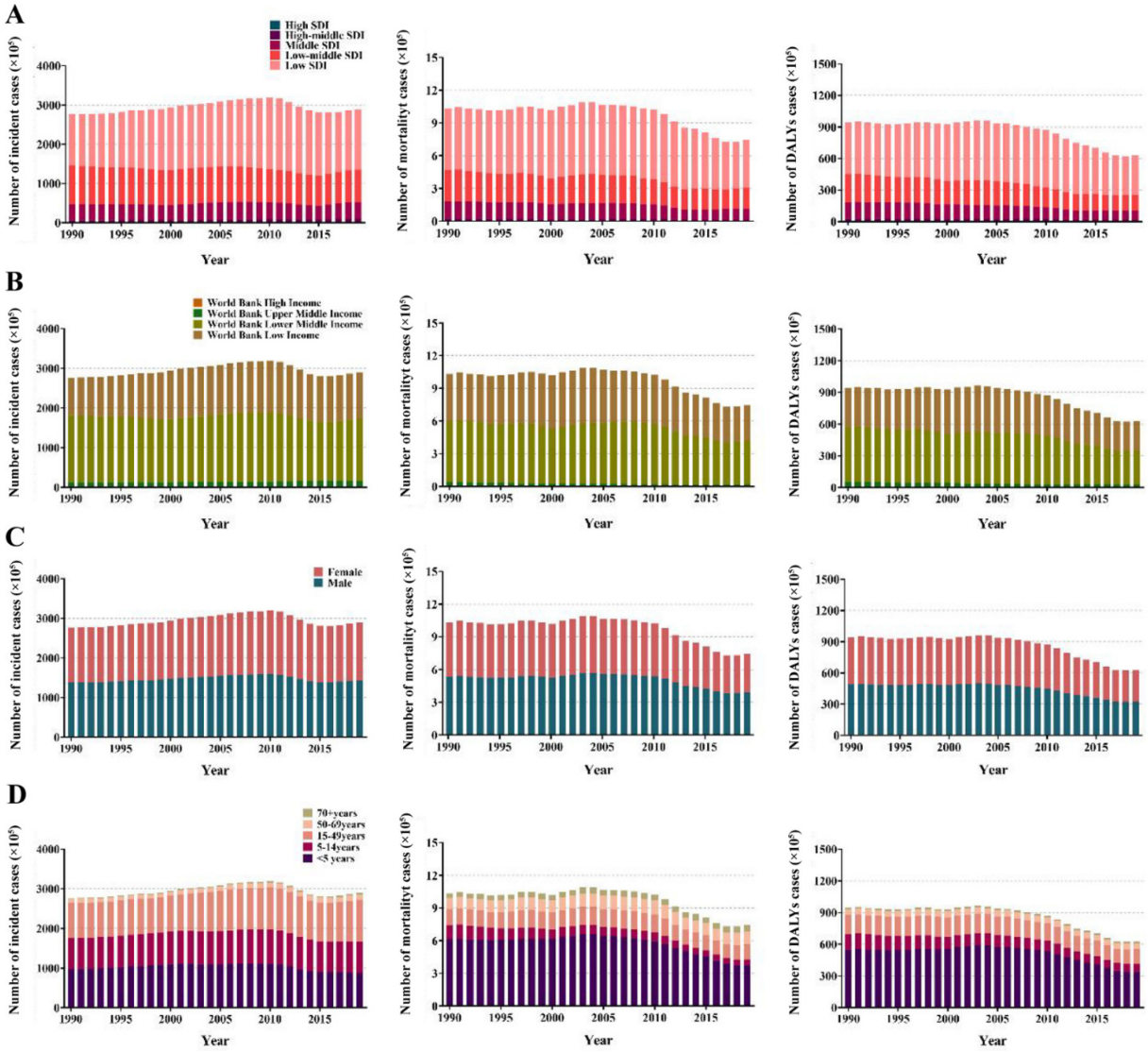

**A:** ASMR for malaria and NTDs worldwide in 2019; **B:** AAPC of ASMR for malaria and NTDs worldwide from 1990 to 2019. ASMR: age-standardized mortality rate; AAPC: average annual percentage change; NTDs: neglected tropical diseases.

**Supplementary Figure 2.** ASDR for malaria and NTDs worldwide in 2019 and AAPC from 1990 to 2019.



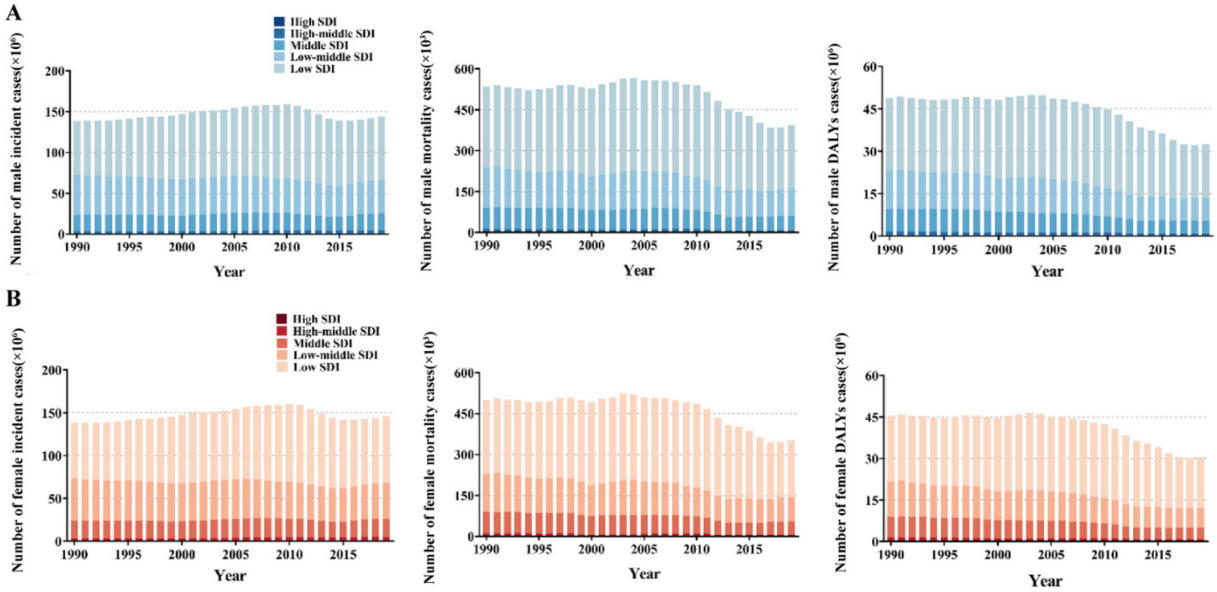

**A:** ASDR for malaria and NTDs worldwide in 2019; **B:** AAPC of ASDR for malaria and NTDs worldwide from 1990 to 2019. ASDR: age-standardized disability-adjusted life years rate; AAPC: average annual percentage change; NTDs: neglected tropical diseases.

**Supplementary Figure 3.** Trends in incident cases, mortality cases, and DALYs with different characteristics of malaria and NTDs from 1999 to 2019.



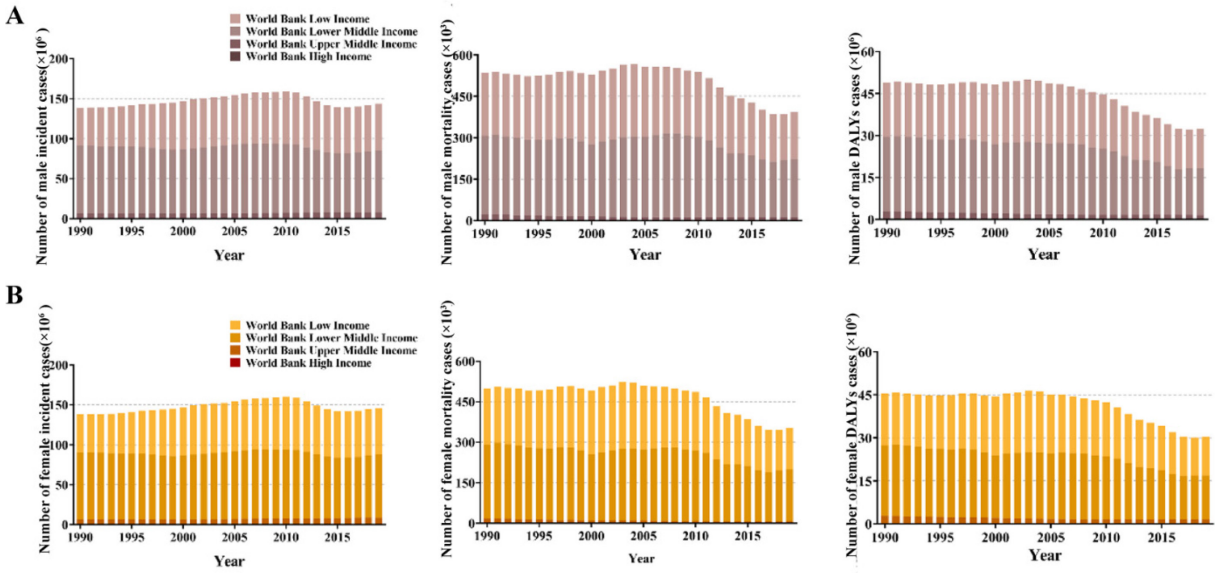

**A:** incident cases: mortality cases: and DALYs of malaria and NTDs in SDI regions from 1990 to 2019; **B:** incident cases: mortality cases: and DALYs of malaria and NTDs in the World Bank income regions from 1990 to 2019; **C:** incident cases: mortality cases: and DALYs of malaria and NTDs by gender from 1990 to 2019; S3D: incident cases: mortality cases: and DALYs of malaria and NTDs by age from 1990 to 2019. DALYs: disability-adjusted life years; NTDs: neglected tropical diseases. SDI, socio-demographic index.

**Supplementary Figure 4.** Subgroup analysis in incident cases, mortality cases, and DALYs of malaria and NTDs for SDI regions from 1990 to 2019.



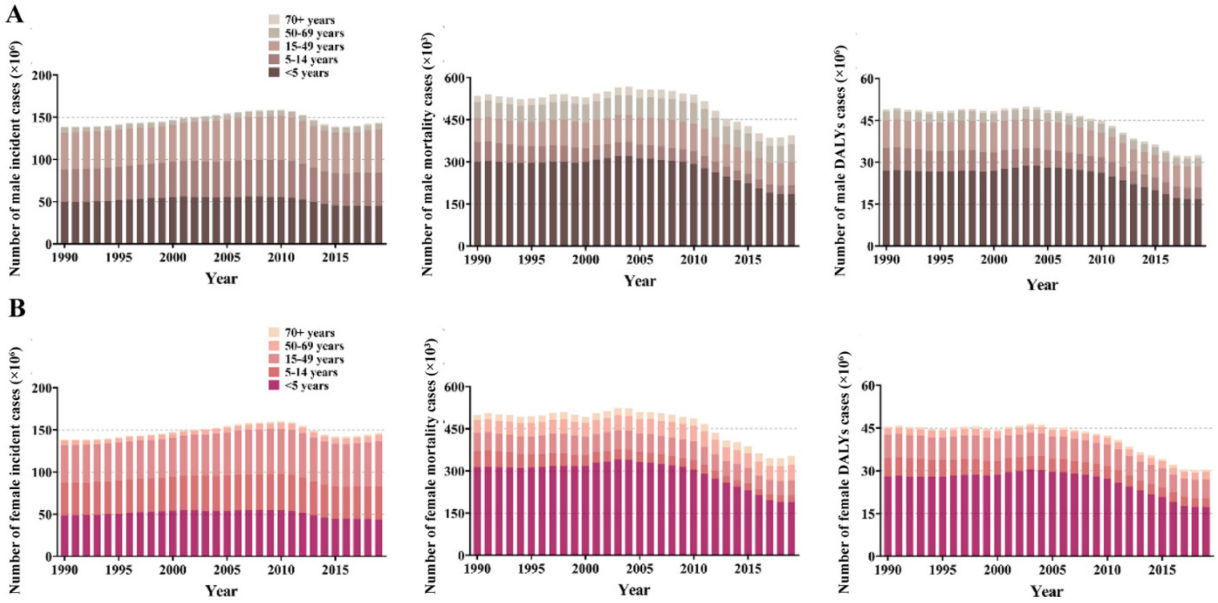

**A:** incident cases: mortality cases: and DALYs of malaria and NTDs among men in SDI region from 1990 to 2019; **B:** incident cases: mortality cases: and DALYs of malaria and NTDs among women in SDI regions from 1990 to 2019. DALYs: disability-adjusted life years; NTDs: neglected tropical diseases; SDI: socio-demographic index.

**Supplementary Figure 5.** Subgroup analysis in incident cases, mortality cases, and DALYs of malaria and NTDs for the World Bank income regions from 1990 to 2019.



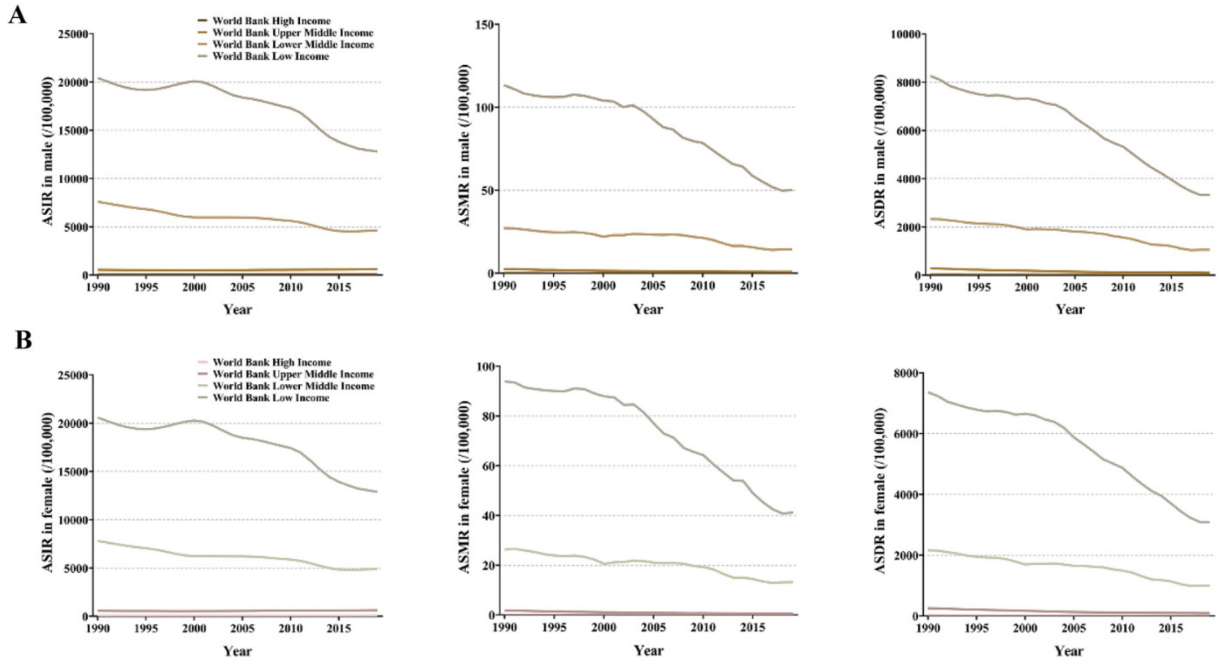

**A:** incident cases: mortality cases: and DALYs of malaria and NTDs among men for the World Bank income regions from 1990 to 2019; **B:** incident cases: mortality cases: and DALYs of malaria and NTDs among women for the World Bank income regions from 1990 to 2019. DALYs: disability-adjusted life years; NTDs: neglected tropical diseases.

**Supplementary Figure 6.** Subgroup analysis in incident cases, mortality cases, and DALYs of malaria and NTDs for different ages from 1990 to 2019.



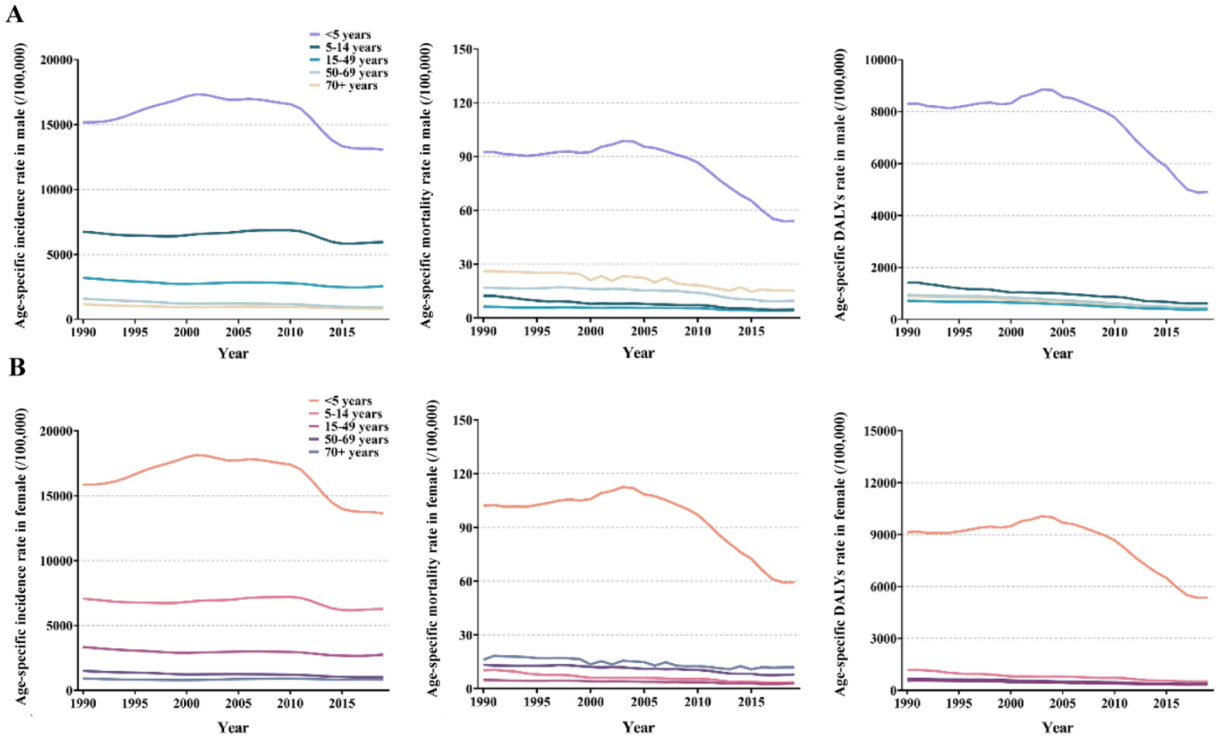

**A:** incident cases: mortality cases: and DALYs of malaria and NTDs among men of different ages from 1990 to 2019; **B:** incident cases: mortality cases and DALYs of malaria and NTDs among women of different ages from 1990 to 2019. DALYs: disability-adjusted life years; NTDs: neglected tropical diseases.

**Supplementary Figure 7.** Subgroup analysis in ASIR, ASMR and ASDR of malaria and NTDs for World Bank income region from 1990 to 2019.



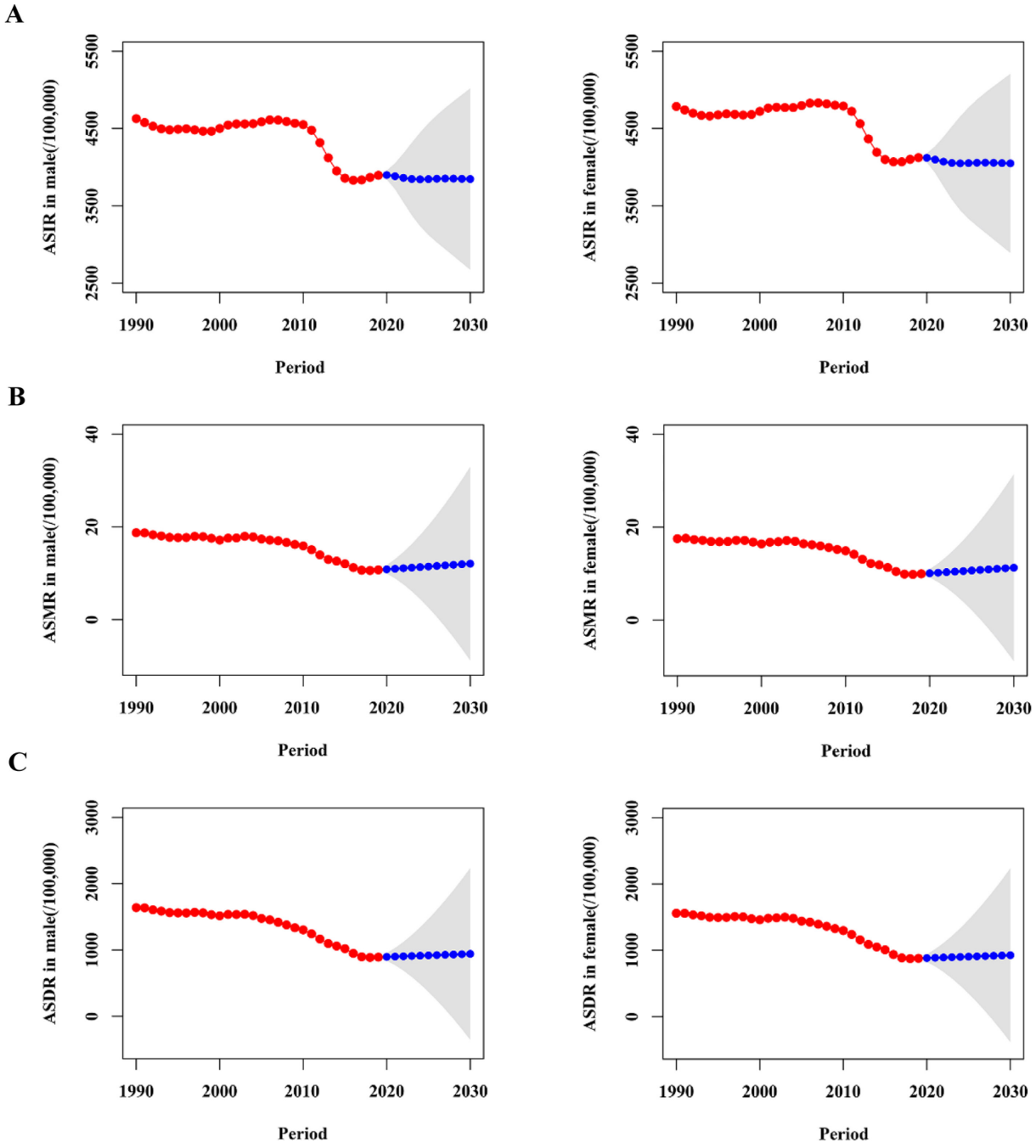

**A:** ASIR: ASMR: and ASDR of malaria and NTDs among men for World Bank income regions from 1990 to 2019; **B:** ASIR: ASMR: and ASDR of malaria and NTDs among women for World Bank income regions from 1990 to 2019. ASIR: age-standardized incidence rate; ASMR: age-standardized mortality rate; ASDR: age-standardized disability-adjusted life years rate; NTDs: neglected tropical diseases.

**Supplementary Figure 8.** Subgroup analysis in disease burden of malaria and NTDs for different ages from 1990 to 2019.



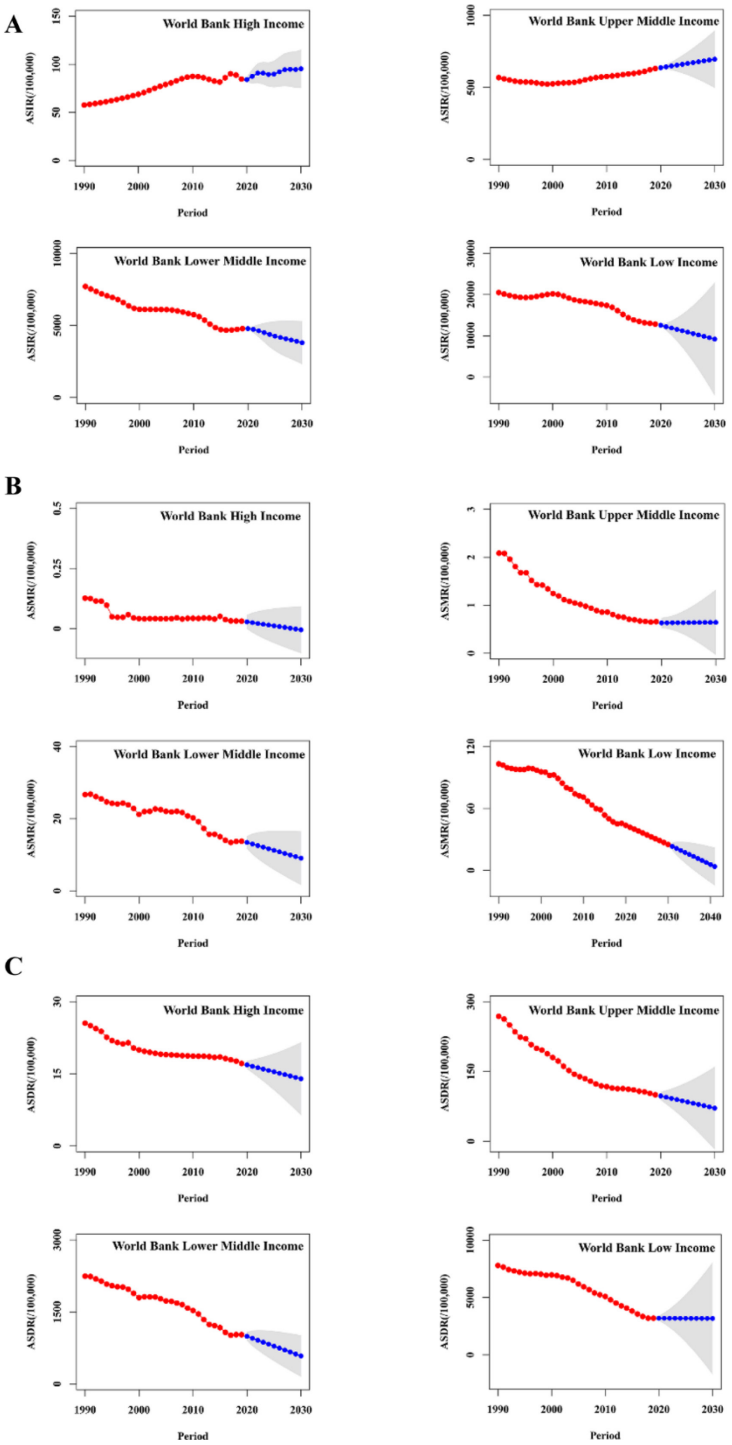

**A:** disease burden of malaria and NTDs among men of different ages from 1990 to 2019; **B:** disease burden of malaria and NTDs among women for different ages from 1990 to 2019. ASIR: age-standardized incidence rate; ASMR: age-standardized mortality rate; ASDR: age-standardized disability-adjusted life years rate; NTDs: neglected tropical diseases.

**Supplementary Figure 9.** Predictions of malaria and NTDs in different genders from 2020 to 2030.



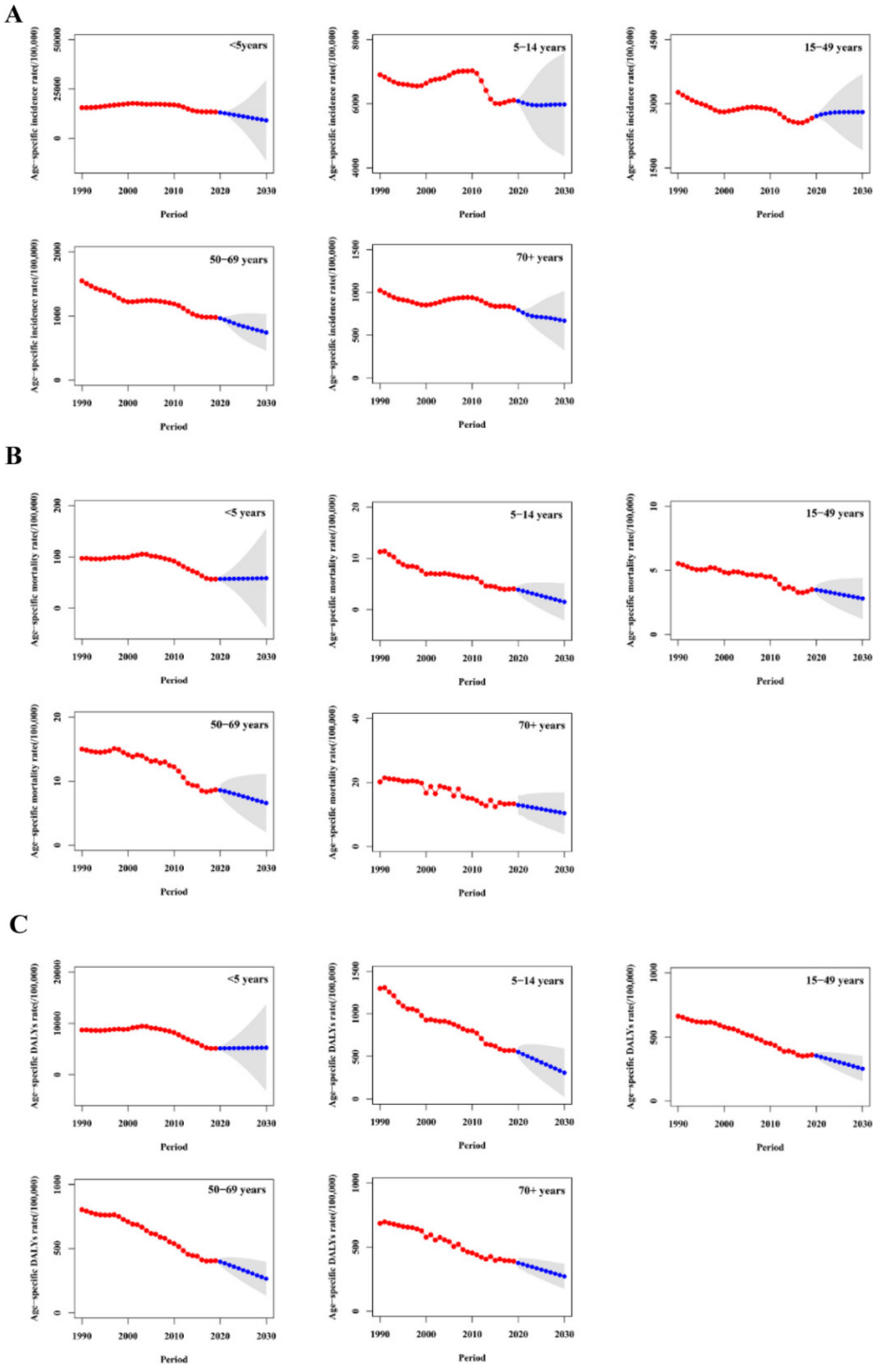

**A:** ASIR of malaria and NTDs in different genders from 2020 to 2030; **B:** ASMR of malaria and NTDs in different genders from 2020 to 2030; **C:** ASDR of malaria and NTDs in different genders from 2020 to 2030. The red dots represent the corresponding rates from 1990 to 2019: the blue dots represent the projected results from 2020 to 2030: and the shading represents the 95% confidence intervals. ASIR: age-standardized incidence rate; ASMR: age-standardized mortality rate; ASDR: age-standardized disability-adjusted life years rate; NTDs: neglected tropical diseases.

**Supplementary Figure 10.** Predictions of malaria and NTDs in different World Bank income regions from 2020 to 2030.




**A:** ASIR of malaria and NTDs in different World Bank income regions from 2020 to 2030; **B:** ASMR of malaria and NTDs in different World Bank income regions from 2020 to 2030; **C:** ASDR of malaria and NTDs in different World Bank income regions from 2020 to 2030. The red dots represent the corresponding rates from 1990 to 2019: the blue dots represent the projected results from 2020 to 2030: and the shading represents the 95% confidence intervals. ASIR: age-standardized incidence rate; ASMR: age-standardized mortality rate; ASDR: age-standardized disability-adjusted life years rate; NTDs: neglected tropical diseases.

**Supplementary Figure 11.** Predictions of malaria and NTDs in different ages from 2020 to 2030.




**A:** ASIR of malaria and NTDs in different ages from 2020 to 2030; **B:** ASMR of malaria and NTDs in different ages from 2020 to 2030; **C:** ASDR of malaria and NTDs in different ages from 2020 to 2030. The red dots represent the corresponding rates from 1990 to 2019: the blue dots represent the projected results from 2020 to 2030: and the shading represents the 95% confidence intervals. DALYs: disability-adjusted life years; NTDs: neglected tropical diseases; ASIR: age-specific incidence rate; ASMR: age-specific mortality rate; ASDR: age-specific disability-adjusted life years rate.