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Forecasted Trends in the Burden of *Trichuris trichiura* in Afghanistan, Iran, and Pakistan: A Regional Epidemiological Modeling Study

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ABSTRACT

Background: Trichuriasis, caused by *Trichuris trichiura*, remains a significant public health concern in many low- and middle-income countries. Understanding its future burden is essential for informed resource allocation and intervention planning. We aimed to model and compare the projected age-standardized prevalence rates (ASPR) of trichuriasis in Afghanistan, Iran, and Pakistan from 2023 to 2040.

Methods: We extracted sex-specific ASPR data for *T. trichiura* from 1990 to 2023 from the Global Burden of Disease Study 2023 (GBD 2023). A cubic spline regression model was then fitted to the historical data using a least-squares approach. The calibrated model was subsequently used to project ASPR and its 95% confidence intervals (CIs) through 2040 for each country and sex.

Results: In 2023, Pakistan had a substantially higher ASPR of 8,186.1 per 100,000, approximately 19 and 29 times higher than Afghanistan (424.7) and Iran (284.6), respectively. By 2040, all countries are projected to experience declines. Afghanistan shows the steepest relative decline, with a reduction of 61.9%, reaching an ASPR of 161.7 per 100,000 by 2040, and Pakistan the largest absolute reduction (45.2% to 4,488.9 per 100,000). Minor but consistent male-biased prevalence disparities were observed throughout the projection period.

Conclusion: While the burden of trichuriasis is projected to decline substantially in all three countries by 2040, stark disparities in baseline prevalence and rates of decline persist. Pakistan is projected to retain a disproportionately high absolute burden. These findings underscore the need for intensified, context-specific public health strategies, including sustained mass drug administration (MDA) and improvements in water, sanitation, and hygiene (WASH) infrastructure, to accelerate progress towards elimination.

Keywords: Trichuriasis; Projection; Age-standardized prevalence rate; South Asia; Global Burden of Disease

Introduction

Soil-transmitted helminths (STHs), including trichuriasis caused by the whipworm *Trichuris trichiura*, are among the most prevalent neglected tropical diseases (NTDs) globally, affecting an estimated 1.5 billion people [1]. Infection is associated with chronic morbidity,

including abdominal pain, diarrhea, malnutrition, anemia, and impaired cognitive development in children, contributing to a cycle of poverty and diminished human capital [2,3].

Significant progress has been made in reducing the global burden of STH over recent decades, largely driven by expanded mass drug administration (MDA) programs, improvements in socioeconomic conditions, and enhanced water, sanitation, and hygiene (WASH) infrastructure [4,5]. The WHO has set targets for the control and elimination of STH as a public health problem, emphasizing the need for continued surveillance and strategic planning [6]. However, progress is uneven, with substantial heterogeneity in prevalence and intervention success across and within regions [7].

Although global and regional declines in STH infections have been reported, substantial heterogeneity persists across countries and subnational settings. A recent systematic review and meta-analysis of soil-transmitted helminths in low- and middle-income countries demonstrated wide variation on the prevalence estimates between regions and countries, even within the same WHO region, reflecting differences in sanitation coverage, socioeconomic conditions, health system capacity, and implementation intensity of preventive chemotherapy programs [8]. Such heterogeneity is particularly relevant for neighboring countries such as Afghanistan, Iran, and Pakistan, which share ecological and cultural characteristics but differ markedly in political stability, infrastructure, and maturity of control programs. These contrasts suggest that regional averages may obscure country-specific epidemiological trajectories, underscoring the need for comparative, country-level modeling to quantify and explain divergent trends in trichuriasis burden.

Studies from Afghanistan document substantial STH burden among children, with prevalence rates often being high in school-age populations, associated with poverty, inadequate sanitation, and limited infrastructure [9]. Understanding the future trajectories of trichuriasis in these settings is critical for evaluating the long-term impact of current interventions and guiding future policy.

Mathematical modeling has become an indispensable tool in public health for forecasting disease trends, assessing intervention impact, and supporting strategic decision-making [10]. By extrapolating from historical data, models can provide valuable insights into future burdens under current trajectories, highlighting potential challenges and opportunities for acceleration.

We aimed to model and project the age-standardized prevalence of trichuriasis in Afghanistan, Iran, and Pakistan from 2023 to 2040. By comparing baseline burdens, rates of decline, and sex-specific patterns, we seek to elucidate the divergent epidemiological pathways in these countries and inform targeted, context-appropriate strategies for achieving the WHO 2030 NTD road map targets.

Methods

Data sources

To project the future prevalence of *T. trichiura*, sex-disaggregated ASPR data for Afghanistan, Iran, and Pakistan from 1990 to 2023 were obtained from GBD 2023 via the Global Health Data Exchange (GHDx) (https://vizhub.healthdata.org/gbd-results/).

Modeling Approach

A cubic spline regression framework was employed to project *T. trichiura* prevalence through 2040. For each country and sex, the model was fitted to historical ASPR data (1990–2023) using ordinary least squares – an approach that flexibly captures smooth, non-linear temporal trends without imposing strong parametric assumptions [11]. The calibrated model produced forecasts with 95% confidence intervals (CIs) for all estimates. All sta-

tistical analyses and spatial visualizations were performed using R software (version 4.3.1).

Results

The modeling analysis revealed noteworthy disparities in both the current burden and the projected future trajectories of trichuriasis among Afghanistan, Iran, and Pakistan.

Baseline prevalence in 2023

In 2023, the age-standardized prevalence of trichuriasis varied dramatically between the three countries. Pakistan exhibited an extremely high burden, with an ASPR of 8,186.1 cases per 100,000 population (for both sexes combined). This prevalence was approximately 19 times greater than that of Afghanistan (424.7 per 100,000) and 29 times greater than in Iran (284.6 per 100,000). A consistent, albeit modest, gender disparity was noted, with males having slightly higher ASPR values than females across all national settings.

Projected national trends to 2040

The cubic spline model forecasts a continued decline in trichuriasis prevalence in all three countries through 2040, though the pace and magnitude of decline differ substantially (Table 1, Figure 1).

Pakistan is projected to experience the most pronounced absolute reduction. Its ASPR is forecast to fall to 4,488.9 per 100,000 (95% UI: 3,375.2–5,970.2) by 2040, representing a 45.2% decline from its 2023 baseline.

Afghanistan is projected to undergo the steepest relative decline. Its ASPR is expected to decrease by 61.9% to 161.7 per 100,000 (95% UI: 129.8–201.4) by 2040.

Iran shows the most modest projected reduction. Its ASPR is forecast to decline by 20.0% to 227.8 per 100,000 (95% UI: 193.2–268.7) by 2040.

Despite these declines, Pakistan's projected 2040 ASPR remains an order of magnitude higher than the endpoints for Afghanistan and Iran.

Figure 1 illustrates both the historical GBD estimates (1990–2023) and the projected trends (2024–2040), highlighting marked cross-country heterogeneity in baseline prevalence and projected declines, with Pakistan maintaining a substantially higher burden throughout the study period.

Sex-specific projections

The downward trends are consistent for both males and females within each country. The minor baseline differences in prevalence between sexes are maintained proportionally throughout the forecast period. For example, in Pakistan, the ASPR for females is projected to decline by 45.2% and for males by 45.1%, mirroring the overall national trend.

Table 1: Projected age-standardized prevalence rate (ASPR) of trichuriasis in Afghanistan, Iran and Pakistan from 2024 to 2040 and two corresponding percentage change

Sex	*Country*	*2024*	*2025*	*2030*	*2035*	*2040*	*1990 vs.2023*	*2023 vs. 2040*
Both	Afghanistan	398.4 (384.6-412.6)	376.5 (359.6-394.3)	284.0 (256.2-314.9)	214.3 (182.3-251.8)	161.6 (129.7-201.4)	-92.4	-61.9
	Iran	278.5 (271.2-285.9)	275.0 (265.7-284.7)	258.3 (239.0-279.1)	242.5 (214.8-273.8)	227.8 (193.1-268.7)	-69.8	-19.9
	Pakistan	7887.4 (7536.1-8255.2)	7614.4 (7172.7-8083.36)	6384.6 (5583.9-7300.2)	5353.5 (4341.8-6600.9)	4488.9 (3375.1-5970.1)	-64.0	-45.1
Female	Afghanistan	396.8 (383.1-411.0)	375.0 (358.2-392.7)	282.9 (255.1-313.7)	213.4 (181.6-250.8)	161.0 (129.2-200.5)	-92.4	-61.9
	Iran	277.3 (270.1-284.8)	273.9 (264.6-283.5)	257.2 (238.0-278.0)	241.5 (214-272.7)	226.8 (192.3-267.6)	-69.8	-19.9
	Pakistan	7857.5 (7507.5-8223.7)	7585.5 (7145.6-8052.4)	6360.4 (5562.9-7272.2)	5333.18(4325.5-6575.4)	4471.8 (3362.6-5946.9)	-64.1	-45.1
Male	Afghanistan	399.9 (386.1-414.2)	378.0 (361.0-395.8)	285.1 (257.2-316.1)	215.1 (183.0-252.7)	162.2 (130.2-202.1)	-92.4	-61.9
	Iran	279.6 (272.3-287.1)	276.1 (266.7-285.8)	259.3 (239.9-280.2)	243.5 (215.7-275)	228.7 (193.9-269.8)	-69.7	-19.9
	Pakistan	7914.8 (7562.1-8283.9)	7640.9 (7197.6-8111.6)	6407.5 (5603.6-7326.6)	5373.1 (4357.4-6625.6)	4505.8 (3387.6-5993.1)	-64.0	-45.1

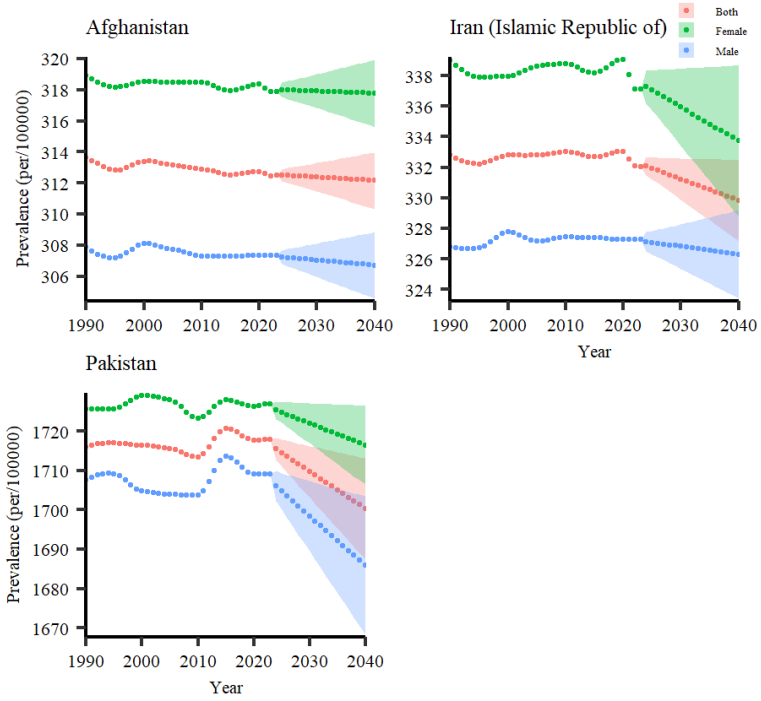

Figure 1: Observed (1990–2023) and projected (2024–2040) age-standardized prevalence rates (ASPR) of trichuriasis in Afghanistan, Iran, and Pakistan. Solid lines represent observed GBD 2023 estimates, while dashed lines indicate model-based projections. Shaded areas denote 95% uncertainty intervals (UIs). Distinct colors are used to differentiate countries

Discussion

This study projects a continued decline in trichuriasis prevalence across Afghanistan, Iran, and Pakistan through 2040. While the direction of the trend is positive and aligns with global goals for NTD control [6], the findings reveal profound heterogeneity in the scale of the current epidemic and the projected pace of progress. This heterogeneity underscores the critical need for nuanced, country-specific public health strategies rather than a one-size-fits-all regional approach.

Regional studies from Pakistan indicate particularly high STH prevalence in some districts and ecological zones, with substantial proportions of the population at risk of infection, consistent with the classification of the country as high burden [12–14].

High population density and inadequate sanitation infrastructure can increase transmission risk for infectious diseases, while climatic conditions such as temperature and rainfall influence vector and parasite dynamics. Additionally, MDA programs may face logistical and community participation barriers that limit sustained, high-coverage implementation [15,16]. In contrast, Iran's lower baseline aligns with its more advanced economic development and historically stronger public health infrastructure. Afghanistan's intermediate baseline is difficult to interpret definitively, as it may reflect a true intermediate burden or, more likely, significant underreporting and surveillance gaps due to decades of conflict and a fragile health system [17,18].

The divergent projected trajectories are equally informative. Afghanistan's steep projected relative decline may reflect the recent scale-up of NTD interventions, including preventive chemotherapy and programmatic integration supported by international partners, which expanded from low and variably measured baselines; however, gaps in reporting and data completeness complicate interpretation of true epidemiological trends and may exaggerate apparent progress over time. In contrast, Iran's more modest projected decline is consistent with patterns observed in countries that have achieved substantial reductions in NTD burden and are encountering "last-mile" challenges, where residual transmission persists in underserved or hard-to-reach populations, and further reductions become slower and resource-intensive as programmes approach elimination thresholds. Pakistan's trajectory, a projected 45 percent decline from a historically high baseline illustrates one of the most significant public health challenges among endemic settings. Even with sustained efforts, Pakistan is expected to retain a high absolute burden by 2040, underscoring a sobering reality: without a massive and sustained escalation of intervention intensity combining high-coverage MDA, robust monitoring and evaluation, and transformative investments in WASH infrastructure, soil-transmitted helminth infections such as trichuriasis will likely remain major causes of morbidity for decades to come.

The persistent, though minor, male-biased prevalence across all settings is consistent with some global epidemiological patterns for STH [19]. This might be linked to behavioral factors leading to differential exposure or to biases in care-seeking and diagnosis. While the disparity is small, its consistency suggests that incorporating gender-sensitive components into health education and active case-finding strategies could yield marginal gains in program efficiency.

The divergent projections necessitate distinct strategic priorities. Pakistan's projected trajectory illustrates the scale of the remaining challenge in high-burden settings. Although a 45% decline in age-standardized prevalence is forecast by 2040, the residual burden (approximately 4,500 cases per 100,000 population) would remain far above the WHO threshold for elimination of soil-transmitted helminthiases as a public health problem, defined as less than 2%

prevalence of moderate-to-heavy intensity infection in at-risk populations. This implies that, under current trajectories, Pakistan is unlikely to achieve elimination targets without substantial intensification of control efforts. Sustained, high-coverage preventive chemotherapy, strengthened monitoring of drug efficacy, and large-scale investments in water, sanitation, and hygiene infrastructure will be essential to reduce transmission to levels compatible with elimination [20].

In Afghanistan, the priority is consolidation and verification. Efforts should focus on maintaining access to MDA where security permits, while simultaneously investing in community-based surveillance and building a functional health information system to establish a more reliable baseline and monitor true progress [21]. Iran's lower baseline prevalence is consistent with its relatively higher level of socioeconomic development, broader access to improved sanitation, and stronger primary healthcare infrastructure, factors that have been consistently associated with reduced soil-transmitted helminth transmission globally [1,3].

The divergent projected trajectories also have important implications for the WHO 2030 NTDs roadmap. While Iran appears to be approaching a low-burden, near-elimination phase and Afghanistan may achieve substantial relative reductions, Pakistan is projected to retain a disproportionately high burden. Such persistence raises the risk of Pakistan functioning as a regional hotspot, potentially undermining broader regional elimination goals through continued transmission, population movement, and reinfection across borders. These findings highlight that achieving the WHO 2030 targets will require not only national progress but also regional coordination, with intensified support for high-burden countries to prevent persistent foci of transmission.

This study had several limitations. First, the projections are extrapolations based on historical trends and assume continuity of past patterns; they cannot account for future disruptions such as political instability, climate change–driven shifts in transmission, programmatic interruptions, or the emergence of anthelmintic resistance. Second, the accuracy of the projections depends on the quality of the underlying GBD estimates, which are themselves derived from heterogeneous surveillance and survey data and may be affected by underreporting, particularly in conflict-affected and hard-to-reach settings such as Afghanistan. Third, the spline-based statistical approach is descriptive and does not explicitly model transmission dynamics or intervention effects (e.g., MDA coverage or WASH improvements). Finally, the findings are specific to Afghanistan, Iran, and Pakistan and may not be generalizable to other endemic regions with different epidemiological or programmatic contexts.

Conclusion

Although the projected decreases are promising and reflect the effects of sustained control measures, progress toward elimination remains uneven. The substantial residual burden anticipated in Pakistan highlights that trichuriasis continues to disproportionately affect impoverished populations. Achieving future success across the region will require not only ongoing political commitment and international support but also tailored interventions that account for the specific epidemiological and social determinants in each country.

Ethics approval

Ethical approval was not required.

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Conflicts of interest

The authors declare no competing interests.

Data availability statement

All data used in this study are publicly available from the GBD 2023 via the GHDx.

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