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Projected Burden of Cystic Echinococcosis in Afghanistan, Iran, and Pakistan: A Regional Modeling Study

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ABSTRACT

Background: We aimed to estimate and forecast the sex-specific and national burden of cystic echinococcosis (CE) in Iran, Afghanistan, and Pakistan through 2040.

Methods: We utilized data from the Global Burden of Disease Study 2023 on cystic echinococcosis incidence, prevalence, and mortality for Iran, Afghanistan, and Pakistan between 1990 and 2023. An illness–death model, a compartmental dynamic model, was applied to project the age-standardized prevalence rate (ASPR) of CE through 2040. The model accounted for sex-specific epidemiological variations, enabling comparative regional and temporal analyses.

Results: Between 1990 and 2023, all three countries exhibited a general decline in cystic echinococcosis burden, with projections indicating continued decreases through 2040. Iran showed the highest age-standardized prevalence rate in 2023 (7.39 per 100,000), followed by Afghanistan (5.28) and Pakistan (0.95). By 2040, Afghanistan and Pakistan are expected to experience marked reductions of 48.15% and 49.28%, respectively, whereas Iran is projected to decline more modestly by 11.65%. Female prevalence is anticipated to decrease sharply in Afghanistan (−56.34%) and Pakistan (−51.10%), but remain relatively unchanged in Iran (+1.90%), suggesting persistent gender-specific transmission dynamics.

Conclusion: Despite overall declining trends, substantial heterogeneity persists across countries and between sexes. The steeper projected declines in Afghanistan and Pakistan may reflect recent improvements in zoonotic control, while Iran's slower progress, especially among females, underscores ongoing exposure and inequitable access to preventive interventions. Sustained, gender-sensitive, and regionally coordinated One Health strategies are essential to further reduce cystic echinococcosis burden and achieve equitable health outcomes across the region.

Keywords: Cystic echinococcosis; *Echinococcus granulosus;* Disease burden; Epidemiology; One Health

Introduction

Cystic echinococcosis (CE) is a zoonotic parasitic infection in humans caused by the larval form of *Echinococcus granulosus* (dog tapeworm). It affects over one million people worldwide and results in annual economic losses surpassing $3 billion [1,2]. According to the WHO, CE is recognized as one of the 17 neglected tropical diseases (NTDs) that predominantly affect impoverished populations in developing regions [2]. According to estimates from the WHO Foodborne Disease Burden Epidemiology Reference Group, CE is responsible for a significant global health burden, leading to approximately 19,300 deaths annually and accounting for around 871,000 disability-adjusted life years (DALYs) lost each year [3].

It is a globally distributed helminthic infection found on every continent except Antarctica [4]. CE is most prevalent among humans and animals in Australia, South America, Central Asia, northern and eastern Africa, and the Mediterranean area [5–7]. It is most prevalent in low-income pastoral areas where livestock such as sheep are raised and dogs are kept near households for herding or guarding. In these settings, dogs are frequently fed raw offal, and their populations often remain large due to cultural or religious norms that limit population control measures [8]. Infection rates in these communities primarily depend on how common the parasite is in animal offal and the level of contact between sheep and dogs [9,10].

In the life cycle of *E. granulosus*, domestic dogs are the primary definitive hosts, acquiring infection by eating organs of infected animals containing hydatid cysts. Inside dogs, the cysts mature into adult tapeworms, and eggs are shed in feces, contaminating the environment. These eggs remain viable for up to a year and infect intermediate hosts such as sheep, cattle, goats, and pigs. Humans become infected by accidentally ingesting food or water contaminated with dog feces [6,7,11].

Hydatid cysts can develop in various organs, but they most frequently occur in the liver (about 70% of cases) and the lungs (around 20%) [12]. Symptomatic cases usually require surgical intervention, whereas asymptomatic infections often remain undetected until the cysts enlarge [12–14]. Currently, the main preventive measures against CE include livestock vaccination and routine deworming of dogs. Because infected livestock often exhibit few or no clinical signs, successful control programs demand coordinated, multisectoral efforts to address implementation challenges [15,16].

In the Middle East and Central Asia, CE is still endemic, especially in Iran, Afghanistan, and Pakistan, which share similar ecological and socioeconomic conditions conducive to the parasite's life cycle. In Iran, CE is a well-documented zoonosis with reports of human seroprevalence ranging from 1% to over 7% depending on the region, and with a pooled prevalence of 5.6% among slaughtered livestock, indicating ongoing transmission [17]. Data suggest that rural women and housewives have a high rate of exposure because of frequent contact with domestic dogs and livestock [17,18].

Diagnostic infrastructure is limited in Afghanistan, and underreporting is extensive, obscuring the true burden. Available data from this nation indicate a high prevalence, especially in rural provinces where livestock husbandry is central to livelihoods [19,20].

Similarly, Pakistan continues to report human and animal CE cases from all provinces, with seroprevalence rates of 0.6% to 3.1% in humans and up to 10% in livestock, reflecting substantial zoonotic potential [21]. Fragmented control efforts, poor offal management, and limited veterinary resources remain significant challenges for both Afghanistan and Pakistan [19,21].

Given these shared epidemiological features, CE in this tri-national region represents a One Health challenge that transcends borders. The continuous interaction of humans, livestock, and dogs, coupled with informal cross-border livestock trade and population movements, sustains endemic transmission cycles. However, few comparative studies have systematically assessed and projected the disease burden across these countries.

Although control programs have been implemented in various countries and regions, hydatidosis remains widespread across extensive geographic areas [22]. The increasing incidence of CE underscores the importance of assessing both the current and projected prevalence of the disease, which can guide evidence-based policy decisions, optimize health system planning, and improve resource allocation.

We aimed to address this gap by estimating and forecasting the burden of CE in Afghanistan, Iran, and Pakistan from 1990 to 2040, using the illness–death model (IDM) and sex-specific Global Burden of Disease (GBD 2021) data. The results are intended to provide a regional comparative framework to inform targeted, gender-sensitive, and coordinated One Health interventions for CE control

Materials and Methods

Study design and data sources

To project the future burden of CE, epidemiological information was obtained from GBD 2021, available via the Global Health Data Exchange (GHDx) repository (https://vizhub.healthdata.org/gbd-results/). For Afghanistan, Iran, and Pakistan, the dataset provided sex-specific, age-standardized data on CE incidence, prevalence, and total and cause-specific mortality between 1990 and 2021. Additional demographic data required for population-based projections were obtained from the GHDx population projection platform (https://vizhub.healthdata.org/population-forecast/).

Modeling approach

We applied an illness-death model (IDM), a compartmental framework based on a system of discrete-time ordinary differential equations as described earlier.
(https://www.frontiersin.org/journals/epidemiology/articles/10.3389/fepid.2022.903652/full).
The model simulated transitions between three health states: susceptible, active disease, and death. For susceptible individuals, transitions included progression to active disease (via the annual incidence rate) or to death from non-CE causes. For individuals with active disease, transitions included remission back to health (reflecting the curable nature of CE) or to CE-related death. All transitions incorporated sex-specific epidemiological rates. Model calibration was performed by fitting model outputs to historical GBD prevalence data (1990–2021) using a least-squares optimization algorithm. This calibrated model was then used to generate annual representative projections of CE prevalence among three countries up to 2040. All age standardized prevalence rate (ASPR) were provided with 95% confidence interval. All analysis were conducted in R software (version 4.3.2).

Results

Regional ASPR trends for CE

Between 1990 and 2023, the epidemiological pattern of CE across the three analyzed countries demonstrated a steady decline. In 2023, Iran recorded the highest age-standardized prevalence rate (ASPR) at 7.39 per 100,000, followed by Afghanistan (5.28) and Pakistan (0.95). In all countries, females consistently exhibited higher prevalence rates than males. Projections indicate a continued and notable reduction in ASPR across the region by 2040, although the rate and extent of this decline are expected to differ considerably by country and sex (Table 1).

Table 1: Projected age-standardized prevalence rate of cystic echinococcosis in three neighboring countries from 2023 to 2040

Countries	*Sex*	*2024*	*2025*	*2030*	*2035*	*2040*	*1990 vs. 2023*	*2023 vs. 2040*
Afghanistan	Both	4.969 (4.9-5.04)	4.788 (4.71-4.87)	3.975 (3.85-4.1)	3.3 (3.15-3.46)	2.739 (2.58-2.91)	-14.745	-48.150
	Female	6.063 (5.96-6.17)	5.784 (5.66-5.91)	4.574 (4.39-4.77)	3.617 (3.4-3.84)	2.86 (2.64-3.1)	-12.586	-56.344
	Male	3.844 (3.82-3.87)	3.784 (3.76-3.81)	3.499 (3.45-3.55)	3.235 (3.17-3.31)	2.992 (2.91-3.08)	-16.155	-24.072
Iran	Both	8.055 (7.68-8.45)	7.95 (7.51-8.42)	7.444 (6.67-8.31)	6.97 (5.92-8.21)	6.527 (5.25-8.12)	-10.993	-11.650
	Female	9.558 (8.83-10.35)	9.476 (8.6-10.43)	9.076 (7.54-10.92)	8.693 (6.6-11.45)	8.326 (5.77-12.01)	-4.436	1.899
	Male	6.541 (6.44-6.64)	6.41 (6.29-6.53)	5.792 (5.59-6.01)	5.234 (4.96-5.53)	4.73 (4.4-5.08)	-18.052	-28.518
Pakistan	Both	0.895 (0.88-0.91)	0.86 (0.85-0.87)	0.709 (0.69-0.73)	0.583 (0.56-0.61)	0.48 (0.46-0.51)	-19.099	-49.278
	Female	1.011 (1-1.03)	0.971 (0.95-0.99)	0.791 (0.77-0.82)	0.645 (0.61-0.68)	0.525 (0.49-0.56)	-20.476	-51.097
	Male	0.791 (0.78-0.8)	0.763 (0.75-0.77)	0.637 (0.62-0.65)	0.531 (0.51-0.55)	0.443 (0.42-0.46)	-18.280	-46.828

Country-specific ASPR trajectories

Afghanistan is anticipated to undergo the most significant reduction in the burden of cystic echinococcosis. The overall ASPR is expected to decline from 5.28 in 2023 to 2.74 (95% UI: 2.58–2.91) by 2040, reflecting a substantial 48.15% decrease. This downward trend is particularly notable among females, with a projected reduction of 56.34%, compared to a 24.07% decrease among males (Table 1).

Pakistan exhibits a similarly steady and substantial downward trend. The overall ASPR is projected to decrease from 0.95 in 2023 to 0.48 (95% UI: 0.46–0.51) by 2040, marking a 49.28% reduction. The decline is expected to be slightly more pronounced among females (−51.10%) compared to males (−46.83%) (Table 1).

Although Iran also demonstrates an overall downward trend, the pattern appears more moderate and variable. The total ASPR is projected to decline by 11.65%, decreasing from 7.39 to 6.53 (95% UI: 5.25–8.12). However, among Iranian females, the prevalence rate is expected to remain nearly unchanged, with a slight increase of 1.90%. In contrast, a marked reduction of 28.52% is anticipated among Iranian males (Table 1).

Comparative analysis of country trajectories

The projected trends indicate distinct public health trajectories across these neighboring countries. Although all three are expected to follow an overall downward trend, the decline in disease burden is projected to be considerably steeper in Afghanistan (−48.15%) and Pakistan (−49.28%) than in Iran (−11.65%). A notable divergence appears in the sex-specific projections: while female prevalence is anticipated to decrease sharply in Afghanistan and Pakistan, it is expected to remain relatively unchanged in Iran. This contrast, particularly among females, points to possible differences in zoonotic control measures, accessibility of veterinary and public health services, or evolving risk factors that deserve further exploration (Figure 1).

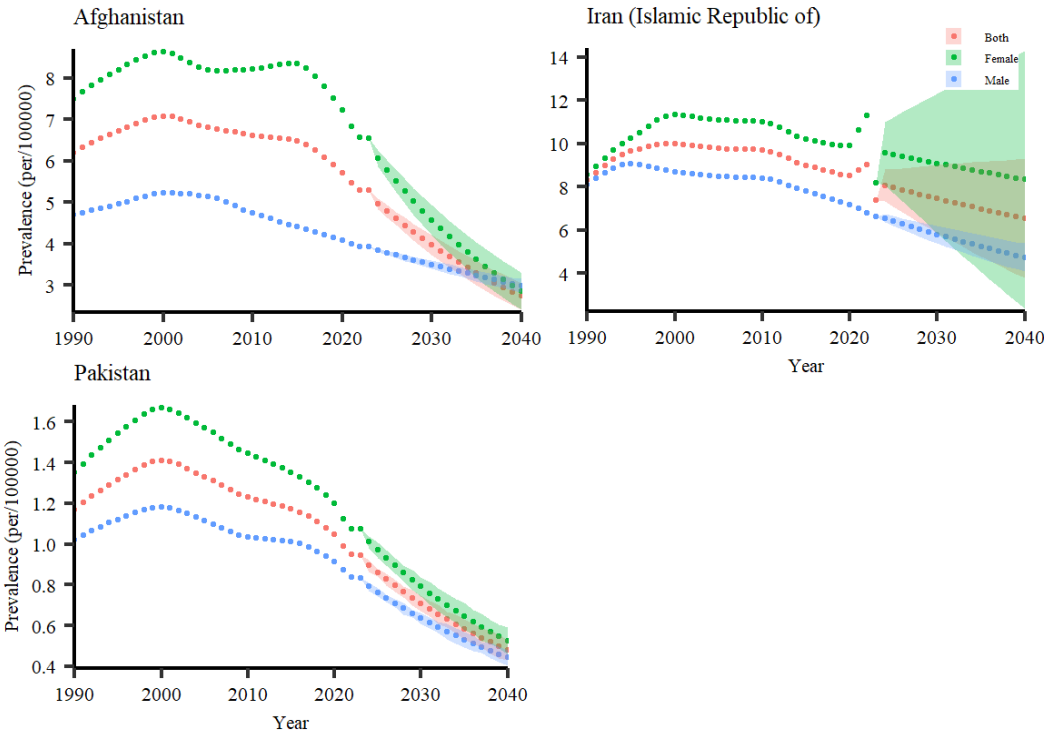

Figure 1: Observed and projected age-standardized prevalence rate of cystic echinococcosis in three neighboring countries between 1990-2040

Discussion

The present study provides comparative projections of CE burden across Afghanistan, Iran, and Pakistan from 1990 to 2040, based on the sex-specific and ASPR. While all three countries are estimated to follow a declining trend in ASPR, the rate, extent and sex-specific patterns of decline are substantially different. These differences have public health policy, zoonotic prevention of disease, livestock husbandry and health equity implications.

The sharp expected declines in ASPR for Afghanistan and Pakistan are suggestive of favorable dynamics in underlying transmission and/or control efforts, possibly reflecting improvements in dog deworming, livestock management, and public health education in parts of Central Asia [19]. In contrast, Iran demonstrates a more modest reduction, indicating either slower progress in CE control or persistent transmission in specific demographic groups (e.g., females) that prevent equalized decline [17].

These findings suggest that, in Pakistan and Afghanistan, interventions, socio-behavioral changes, or livestock/veterinary practices may have been evolving more rapidly or more intensively scaled, thereby driving steeper declines. Alternatively, Iran's lower decline could be a plateau in gains or a higher incidence of more established transmission cycles that are harder to break.

The sex-related projections reveal a large divergence: while female ASPR is projected to drop substantially in Afghanistan and Pakistan (−56.34% and −51.10%, respectively), in Iran female ASPR is projected to be hardly impacted (with a marginal increase of +1.90%) whereas male ASPR is anticipated to decrease by 28.52%. This divergence points toward potential gender differences in exposure, access to

control interventions, or behavior-based risk factors.

The meta-analytic research in Iran has documented higher CE prevalence among women, especially housewives, likely reflecting greater domestic or household contact with sources of infection. This might be attributed to women's more frequent involvement in animal husbandry, home slaughtering, and domestic contact with dogs and livestock well-recognized risk factors for CE. The persistent prevalence among females likely reflects ongoing exposure that is not being adequately addressed by existing control strategies [18,23].

In central Asia, including Iran, Afghanistan and Pakistan, control efforts have been fragmented and are usually under-funded. For example, the region was examined and noted that whereas de-worming of dogs and other interventions have been attempted, they are often uncoordinated and erratic [19].

The steeper declines in Afghanistan and Pakistan might indicate that some of the control efforts are gaining momentum, or host–parasite interactions and animal–human contact are being disrupted in a desirable manner (e.g., higher rates of slaughtering dogs, improved access to veterinarians, or fewer stray dogs) [20]. In contrast, Iran's more gradual decline and female-specific plateauing might reflect either worse enforcement of control in female-dominant exposure contexts, or persisting risk behavior or structural barriers (e.g., culture roles, veterinary care provision, or dog–livestock–human interface) disproportionately affecting women.

Our use of IDM calibrated to GBD 2021 data for CE (1990–2021) provides a structured way to project future prevalence up to 2040, while incorporating sex-specific epidemiological dynamics. The compartmental framework allows simulation of transitions from susceptibility to active disease and to disease-attributable mortality, aligned with the modelling of chronic zoonotic conditions.

However, several limitations should be acknowledged. First, the model draws on aggregated, age-standardized GBD data, which may mask regional heterogeneity (e.g., subnational differences, rural vs urban disparity, nomadic populations). Second, the model assumes that historical trends and sex specific patterns continue into the future this may not hold if key drivers change (e.g., livestock trade, dog population management, conflict/displacement, migration). Third, the projections do not explicitly model intermediate host (livestock) or final host (dog) populations, nor explicitly simulate interventions at the veterinary level this could under- or overestimate future declines. Fourth, these projections are inherently model-based and rely on GBD data that may include uncertainty arising from underreporting, diagnostic variability, and limited surveillance coverage in some countries. The IDM does not explicitly model dog or livestock host dynamics, which may influence CE transmission.

Finally, data quality and diagnostic coverage for CE vary across countries; under-reporting and diagnostic delays may affect the calibration of the model.

The marked declines projected for Afghanistan and Pakistan represent an opportunity: these countries are on a trajectory to significantly reduce the burden of CE, but further effort will be needed to sustain and accelerate progress. Given the higher baseline prevalence and demonstrated reductions among females, interventions should emphasize equity of benefit for females. For Iran, the relative stagnation among females indicates that gender-sensitive control measures should be reviewed and strengthened, such as outreach to rural/nomadic women, safe slaughtering in a domestic setting, dog de-worming programmes targeting female-headed households, and behavioral interventions addressing domestic exposure.

The regional variation in decline trajectories suggests that cross-border coordination might

be useful: nomadic movement of livestock; migration of dogs; illegal slaughtering and informal trade across borders between Afghanistan, Iran, and Pakistan could sustain transmission cycles. Joint one-health initiatives of human health, veterinary services, and community education may leverage synergies.

Further research should investigate the subnational dynamics of CE burden and transmission in each country, including attention to rural vs. urban heterogeneity, nomadic pastoralist populations, and livestock trade networks. Gender-disaggregated studies of dog–livestock–human contact patterns would yield insights into why female prevalence remains elevated in some settings, such as Iran. In addition, assessment of intervention coverage like de-worming of dogs, vaccination of dogs, offal disposal practices, safe slaughter, and meat inspection should be incorporated into modelling frameworks to enable more realistic scenario projections. Lastly, cost-effectiveness analyses of scaled one-health interventions in these settings would underpin resource allocation by policy makers.

Conclusion

The observed projections for CE across Afghanistan, Pakistan and Iran highlight broadly encouraging trends, but also reveal critical heterogeneities particularly by sex and country that warrant focused attention. The sharp projected declines in Afghanistan and Pakistan suggest that considerable progress may be achievable with sustained control efforts, while the more modest decline and female-specific stagnation in Iran underscores the need for targeted, gender-sensitive interventions and enhanced zoonotic control. As CE remains a significant one-health challenge in this region, achieving equitable burden reduction will require coordinated human–animal health strategies, rigorous surveillance and responsive policy measures.

Ethics approval

This study utilized publicly available, aggregated data from the GBD database. No individual or identifiable human or animal data were used; therefore, ethical approval and informed consent were not required.

Data availability statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of interest

The authors declare no competing interests.

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