Integrated Serological And Ultrasonographic Screening Reveals The Burden Of Human Cystic Echinococcosis In Southern Kyrgyzstan: A Population-Based Cross-Sectional Study

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Abstract

Background: Cystic echinococcosis (CE) is a neglected zoonotic disease caused by the larval stage of Echinococcus granulosus sensu lato and remains a major public health problem in many pastoral regions of the world. The Kyrgyz Republic is among the countries hyperendemic for echinococcosis and has one of the highest reported incidences of human echinococcosis worldwide; however, community-based epidemiological studies integrating serological screening, abdominal ultrasonography, and assessment of potential risk factors remain limited. This study aimed to determine the seroprevalence of human cystic echinococcosis and describe the epidemiological characteristics of a rural population in southern Kyrgyzstan.

Methods: A population-based cross-sectional study was conducted in Nookat District, Osh Region, Kyrgyzstan. A total of 1,444 participants underwent standardized epidemiological interviews, abdominal ultrasonography, and serological testing for anti-Echinococcus granulosus IgG antibodies using an enzyme-linked immunosorbent assay (ELISA). Demographic, environmental, and behavioral information was collected through a structured questionnaire. Descriptive statistical analyses were performed to summarize participant characteristics, serological findings, and ultrasonographic abnormalities.

Results: Among the 1,444 participants, the mean age was 32.3 ±19.9 years, and 66.4% were female. ELISA detected 114 seropositive individuals, corresponding to an overall seroprevalence of 7.9% (114/1,444), while 20 participants (1.4%) had equivocal results. Abdominal ultrasonography demonstrated normal findings in 76.5% of participants, whereas 23.5% had abnormal findings, including hepatobiliary, renal, pancreatic, reproductive, and postoperative echinococcosis-related lesions. These findings indicate ongoing exposure to E. granulosus within the study population and highlight the value of community-based screening for identifying both parasitic infection and previously undetected abdominal pathology.

Conclusions: Human cystic echinococcosis remains an important public health concern in southern Kyrgyzstan. Integrated community-based screening using serological testing and abdominal ultrasonography represents a practical approach for assessing disease burden and supporting surveillance in endemic regions. The findings provide baseline epidemiological evidence for future analytical studies investigating modifiable risk factors. They may contribute to the development of targeted One Health strategies for the prevention and control of cystic echinococcosis.

Keywords: Cystic echinococcosis; Echinococcus granulosus; Seroprevalence; ELISA; Ultrasonography; Cross-sectional study; Kyrgyzstan; One Health.

Introduction

Cystic echinococcosis (CE) is a chronic zoonotic disease caused by the larval stage of Echinococcus granulosus sensu lato. It remains one of the most important helminthic infections affecting both human and animal health worldwide [1–3]. The parasite maintains a complex life cycle involving domestic and wild canids as definitive hosts and a wide range of ungulates, particularly sheep, goats, cattle, and camels, as intermediate hosts. Humans become accidental intermediate hosts following ingestion of parasite eggs excreted in the feces of infected dogs, resulting in the development of hydatid cysts that predominantly affect the liver and lungs, although virtually any organ may be involved [1, 3, 4]. Because cyst growth is generally slow, infected individuals often remain asymptomatic for many years, delaying diagnosis until cysts are detected incidentally or become clinically significant [1, 5].

Despite advances in diagnosis, treatment, and veterinary control programs, cystic echinococcosis continues to impose a considerable global health and economic burden. The World Health Organization (WHO) classifies CE as a neglected tropical disease because of its persistent transmission in resource-limited settings and its substantial impact on human health, livestock production, and rural livelihoods [4]. Globally, echinococcosis is responsible for hundreds of thousands of disability-adjusted life years (DALYs) annually and causes economic losses exceeding several billion US dollars each year through healthcare expenditures, reduced livestock productivity, and condemnation of infected animal organs [2, 6]. Consequently, the control of CE has become an important component of integrated One Health strategies that simultaneously address human, animal, and environmental health [2, 3].

Central Asia represents one of the world's major endemic regions for cystic echinococcosis. Following the dissolution of the Soviet Union, profound socioeconomic and agricultural changes resulted in a marked resurgence of the disease throughout several former Soviet republics [7, 8].

The collapse of centralized veterinary services, increased home slaughtering of livestock, inadequate disposal of infected viscera, expansion of free-roaming dog populations, and reduced implementation of routine dog deworming programs have collectively facilitated continued parasite transmission in rural communities [3, 7, 9]. As a consequence, Kyrgyzstan has consistently reported one of the highest incidences of human cystic echinococcosis in Central Asia, making the disease an important public health priority [7, 10].

Although national surveillance systems provide valuable information regarding surgically confirmed and clinically diagnosed cases, they are likely to underestimate the true burden of infection because many infected individuals remain asymptomatic for prolonged periods and therefore never present to healthcare facilities [5, 11]. Community-based epidemiological surveys that combine serological testing with abdominal ultrasonography provide a more accurate assessment of disease prevalence by identifying both previous exposure and clinically silent infections [11–13]. Furthermore, such studies enable simultaneous investigation of demographic, environmental, and behavioral factors associated with transmission, thereby generating evidence that can guide locally adapted prevention and control strategies [2, 3].

Several environmental and behavioral factors have been consistently associated with human cystic echinococcosis, including dog ownership, close contact with infected dogs, livestock breeding, home slaughtering practices, feeding dogs raw infected offal, consumption of contaminated food or water, and inadequate hygiene practices [2, 3, 9, 14]. Nevertheless, the relative contribution of these factors varies considerably between endemic regions owing to differences in livestock production systems, cultural practices, socioeconomic conditions, and veterinary infrastructure. Consequently, locally generated epidemiological data remain essential for identifying context-specific determinants of infection and informing evidence-based public health interventions [6, 9].

The incidence of echinococcosis has increased markedly in Kyrgyzstan over the past 30 years and continues to represent a major medical and public health concern in the Kyrgyz Republic. The relevance of this problem is underscored by the absence of a declining trend in the number of affected patients and the persistence of endemic regions, where the incidence ranges from 3.6 to 21.2 cases per 100,000 population [15].

In Kyrgyzstan, published studies have primarily focused on hospital-based patient series, surgical outcomes, or national surveillance statistics, whereas relatively few investigations have examined community-level seroprevalence together with ultrasonographic findings and individual exposure factors within the same study population [7, 10, 16]. Such integrated population-based studies are particularly important because they permit early detection of asymptomatic infections while simultaneously evaluating transmission pathways that may be amenable to targeted intervention. The integration of serological screening with abdominal ultrasonography also enhances disease surveillance by combining immunological evidence of exposure with imaging confirmation of cystic lesions, thereby improving estimates of disease burden in endemic settings [11–13].

Therefore, the present study aimed to determine the seroprevalence of human cystic echinococcosis in a rural population of southern Kyrgyzstan using enzyme-linked immunosorbent assay (ELISA), describe abdominal ultrasonographic findings identified during community-based screening, and investigate demographic, environmental, and behavioral factors associated with serological positivity. The findings are expected to provide epidemiological evidence that supports the development of targeted One Health interventions for the prevention and control of cystic echinococcosis in endemic regions.

2. Materials and Methods

2.1. Study Design and Setting

This population-based cross-sectional study was conducted between July and August 2025 in Nookat District, Osh Region, southern Kyrgyzstan. The study formed part of a community-based screening program designed to evaluate the epidemiology of human cystic echinococcosis (CE) in an endemic rural area. The investigation integrated standardized epidemiological interviews, serological testing for anti-Echinococcus granulosus IgG antibodies, and abdominal ultrasonographic examination to assess both previous exposure and structural evidence of disease.

Nookat District is located in the southwestern part of Kyrgyzstan within Osh Region and is characterized by predominantly rural settlements where animal husbandry constitutes a major source of livelihood. Sheep, goats, cattle, and domestic dogs are commonly raised in close proximity to households, creating ecological conditions favorable for maintaining the transmission cycle of E. granulosus. Previous surveillance studies have identified southern Kyrgyzstan as one of the country's principal endemic areas

for cystic echinococcosis, with continued transmission attributed to traditional livestock management, home slaughtering practices, inadequate disposal of infected offal, and insufficient routine deworming of dogs [7].
Between 2000 and 2022, a total of 860 residents of Nookat District, Osh Region, underwent surgery for echinococcosis at surgical hospitals in Bishkek, Osh, and the regional territorial hospitals of Osh Region. Children younger than 14 years accounted for an average of 17.6% of all operated cases.
The incidence rate of echinococcosis per 100,000 population in Nookat District showed a marked upward trend from 2000 onward. The incidence increased from 13.2 per 100,000 population in 2000 to 19.0 in 2002, reaching 22.5 in 2016. Compared with the beginning of the observation period, the incidence increased by approximately 2.9-fold over the study period.
The long-term average incidence of echinococcosis was 15.7 cases per 100,000 population, with a minimum of 6.0 in 2008 and a maximum of 22.5 in 2016. The corresponding long-term average incidence of alveolar echinococcosis was 1.2 cases per 100,000 population, ranging from 0.1 in 2013 to 2.7 in 2022. During 2012–2022, the incidence of alveolar echinococcosis increased more than fivefold (5.1-fold) compared with the preceding period, while over the period from 2000 to 2018 it increased approximately 1.7-fold.
The study was designed and reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement for cross-sectional studies [17].

Figure 1. Geographic location of the study area in southern Kyrgyzstan.

The map shows the location of Nookat District within Osh Region and the position of Osh Region within Kyrgyzstan. The community-based epidemiological survey was conducted in Nookat District between July and August 2025 (The figure was made by canva app).

2.2. Study Population and Participant Recruitment

Residents of Nookat District were invited to participate in a community-based screening campaign organized in collaboration with local healthcare centers and public health authorities. Recruitment was conducted through announcements at primary healthcare facilities and community outreach activities. Individuals who voluntarily attended the designated screening sites during the study period and met the eligibility criteria were consecutively enrolled after providing written informed consent. Because participation was voluntary, the study sample represents community volunteers rather than a randomly selected population, and this potential source of selection bias was considered during interpretation of the findings. To be eligible for inclusion, participants were required to:

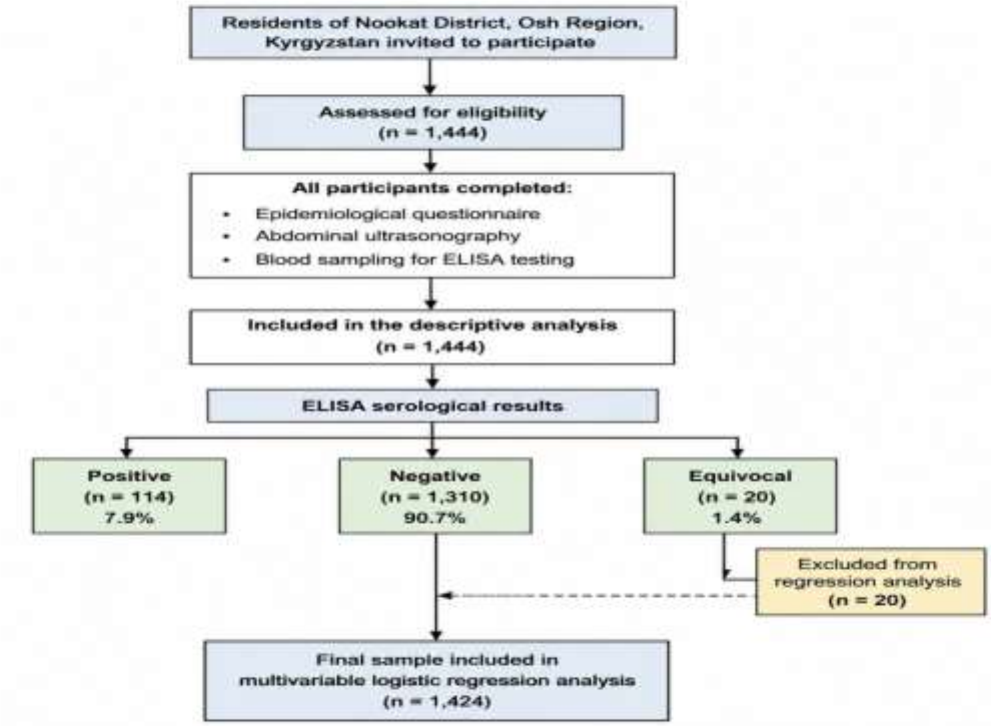
- reside within the study area;
- provide written informed consent (or parental consent for minors);
- complete the standardized epidemiological questionnaire;

• undergo abdominal ultrasonography; and
• provide a venous blood sample for serological analysis.

Participants were excluded if they:
• declined participation;
• had incomplete questionnaire data;
• did not undergo either ultrasonography or blood sampling; or
• had insufficient biological specimens for laboratory analysis.

A total of 1,444 participants satisfied the eligibility criteria and were included in the final analysis.

Figure 2. Flow diagram of participant recruitment, screening, and inclusion in the statistical analyses.



A total of 1,444 community residents from Nookat District, Osh Region, Kyrgyzstan, participated in the study and completed the epidemiological questionnaire, abdominal ultrasonography, and ELISA serological testing for anti-Echinococcus granulosus IgG antibodies. Participants with equivocal ELISA results (n = 20) were excluded from the logistic regression analyses, resulting in a final analytical sample of 1,424 participants (The figure was made by canva app).

2.3. Sample Size

The study included all eligible individuals who participated in the screening campaign during the study period; therefore, no formal sampling procedure was applied. The final sample of 1,444 participants provided adequate precision for estimating the seroprevalence of cystic echinococcosis and sufficient statistical power to evaluate associations between candidate risk factors and serological positivity using logistic regression.

2.4. Data Collection

The structured questionnaire was developed following a review of published epidemiological studies on cystic echinococcosis and was adapted to the local context. The questionnaire was administered through face-to-face interviews by trained healthcare personnel using standardized procedures to minimize interviewer variability. Prior to the study, interviewers received training on questionnaire administration and data recording [2, 3, 14].

The following information was collected:
• age;
• sex;
• place of residence;

- occupation;
- educational status;
- previous abdominal ultrasonography;
- history of previous echinococcosis surgery;
- dog ownership;
- number of dogs owned;
- routine dog deworming;
- feeding dogs raw livestock organs;
- disposal practices for slaughter waste;
- livestock ownership;
- participation in home slaughtering;
- source of drinking water;
- household sanitation practices; and
- other environmental and behavioral factors potentially associated with exposure to E. granulosus.

All questionnaires were reviewed on the day of collection to minimize missing or inconsistent responses.

2.5. Abdominal Ultrasonography

Abdominal ultrasonography was performed by physicians experienced in abdominal imaging who had received prior training in ultrasonographic evaluation of cystic echinococcosis in accordance with WHO-IWGE recommendations.

All participants underwent abdominal ultrasonography performed by experienced physicians using a Mindray M7 portable ultrasound system (Mindray Bio-Medical Electronics Co., Shenzhen, China) equipped with a 3.5–5.0 MHz convex transducer. Standardized scanning protocols were used to evaluate the liver, gallbladder, pancreas, spleen, kidneys, and other abdominal organs.

Whenever imaging findings were considered suggestive of cystic echinococcosis, the lesions were documented descriptively without formal WHO-IWGE stage classification because complete imaging criteria were not available for all cases.

Additional abdominal abnormalities unrelated to echinococcosis were also recorded [1, 11]. Ultrasound findings were classified as:

- normal examination;
- focal hepatic lesion;
- hepatobiliary abnormality;
- renal abnormality;
- pancreatic abnormality;
- reproductive system abnormality;
- postoperative changes compatible with previous CE surgery; or
- suspected parasitic lesion.

Participants with ultrasonographic findings suspicious for cystic echinococcosis or indeterminate cystic lesions were referred for contrast-enhanced computed tomography (CT) when clinically indicated to confirm the diagnosis and further characterize lesion morphology.

2.6. Serological Analysis

Venous blood samples were collected from all participants under aseptic conditions and processed according to standardized laboratory procedures. Serological testing was performed using a commercially available enzyme-linked immunosorbent assay (ELISA) for the detection of anti-Echinococcus granulosus IgG antibodies (An enzyme-linked immunosorbent assay test system for the detection of class G immunoglobulins to single-chamber echinococcus antigens in blood serum (plasma). Vector-Best CJSC, Russia. Echinococcus-IgG-ELISA-BEST D-3356), according to the manufacturer's instructions. The reported diagnostic sensitivity and specificity of the assay were 90% and 100%, respectively.

Positive, negative, and equivocal results were interpreted according to the manufacturer's recommended optical density cut-off values. Internal quality-control procedures were performed for each assay batch using the supplied positive and negative control sera.

2.7. Operational Definitions

For the purpose of statistical analysis, the following operational definitions were applied:

- **Seropositive participant:** a participant with a positive anti-Echinococcus granulosus IgG ELISA result.
- **Dog ownership:** ownership of one or more domestic dogs within the household.
- **Dog deworming:** administration of an anthelmintic drug to household dogs at least once during the preceding year.

- **Home slaughtering:** slaughter of livestock outside licensed slaughterhouse facilities.
- **Unsafe offal disposal:** disposal of infected animal organs in a manner allowing access by domestic dogs.
- **Abnormal ultrasonography:** any abdominal pathological finding identified during ultrasound examination.

2.8. Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 29.0 (IBM Corp., Armonk, NY, USA).
Continuous variables were assessed for normality using the Shapiro–Wilk test and summarized as mean ±standard deviation (SD) or median with interquartile range (IQR), as appropriate, Age was treated as a continuous variable throughout the regression analyses. Categorical variables were presented as frequencies and percentages.
Differences between seropositive and seronegative participants were evaluated using Pearson's chi-square test or Fisher's exact test for categorical variables and the independent-samples t-test or Mann–Whitney U test for continuous variables.
Variables with a P-value < 0.20 in univariable analysis, together with variables considered epidemiologically relevant based on previous literature, were entered into a multivariable logistic regression model to identify independent predictors of seropositivity. Associations were reported as adjusted odds ratios (aORs) with 95% confidence intervals (95% CIs).
Data completeness was assessed before analysis. Participants with missing information for variables included in a specific analysis were excluded from that analysis using complete-case analysis. No multiple imputation procedures were performed because the proportion of missing data was low.
Potential multicollinearity among explanatory variables was evaluated using the variance inflation factor (VIF). Model calibration was assessed using the Hosmer–Lemeshow goodness-of-fit test, and model discrimination was evaluated by calculating the area under the receiver operating characteristic (ROC) curve (AUC).
A two-sided P-value < 0.05 was considered statistically significant.

2.9. Ethical Considerations

The study protocol was reviewed and approved by the Ethics Committee of the Scientific and Production Association "Preventive Medicine" of the Ministry of Health of the Kyrgyz Republic (Extract from Minutes No. 1, dated February 19, 2010), in accordance with the applicable national ethical requirements.
Written informed consent was obtained from all adult participants before enrollment. For participants younger than 18 years, written consent was obtained from a parent or legal guardian. All procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki and its subsequent amendments.
Participant confidentiality was maintained by assigning unique study identification numbers and removing all personally identifiable information before statistical analysis.

3. Results

3.1. Characteristics of the Study Population

A total of 1,444 participants were included in the final analysis. The mean age of the study population was 32.3 ±19.9 years, with a median age of 32 years (range: 2–89 years). Female participants constituted 66.4% (n=959) of the study population, whereas 33.6% (n = 485) were male.

The demographic and epidemiological characteristics of the participants are summarized in **Table 1**.

Table 1. Baseline characteristics of the study population (N = 1,444)

Characteristic	Value
Total participants	1,444
Age (years), mean ± SD	32.3 ± 19.9
Median age (range)	32 (2–89)
Sex	
Female	959 (66.4%)
Male	485 (33.6%)

A total of 1,444 participants were enrolled in the study. The mean age was 32.3 ±19.9 years, with a median age of 32 years (range, 2–89 years). Females comprised 959 (66.4%) of the study population, while 485 (33.6%) were males. The baseline demographic characteristics of the participants are summarized in Table 1.

3.2. Serological Findings

Among the 1,444 participants included in the study, 114 tested positive for anti-Echinococcus granulosus IgG antibodies, corresponding to an overall seroprevalence of 7.9%. A total of 1,310 participants (90.7%) tested negative, whereas 20 participants (1.4%) had equivocal serological results. The overall seroprevalence with its corresponding 95% confidence interval is presented in Table 2.

Table 2. Serological results for anti-Echinococcus granulosus IgG antibodies (N = 1,444)

ELISA result	n	%	95% CI
Positive	114	7.9	**6.6–9.4**
Negative	1,310	90.7	—
Equivocal	20	1.4	—

*95% confidence interval calculated only for the prevalence estimate.

3.3. Ultrasonographic Findings

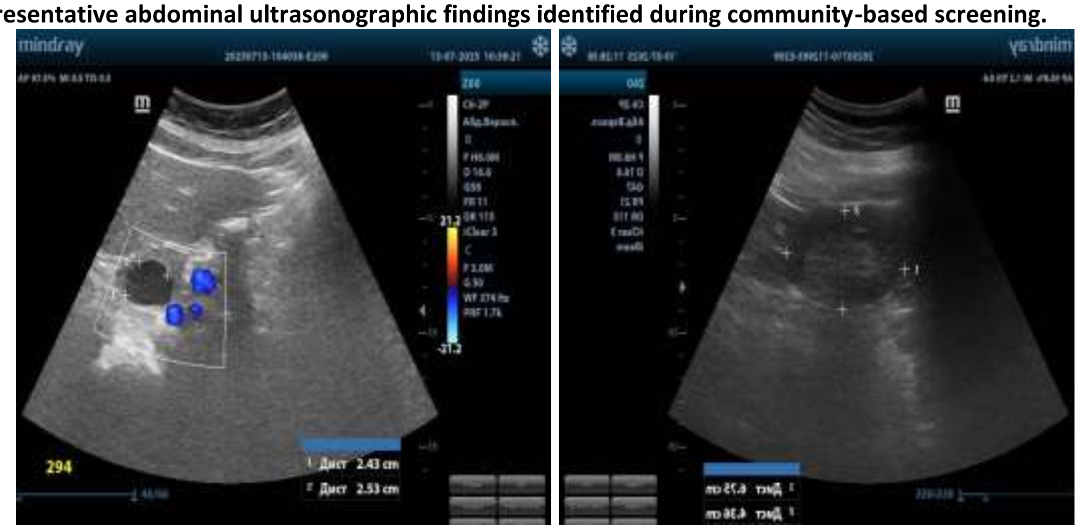
Abdominal ultrasonography was successfully performed in all 1,444 participants. Overall, 340 participants (23.5%) had one or more abnormal ultrasonographic findings.

The majority of these represented incidental non-echinococcal abnormalities, with hepatobiliary abnormalities being the most frequent (11.4%), followed by renal abnormalities (6.7%), gallbladder disease (2.5%), pancreatic abnormalities (0.7%), and reproductive system abnormalities (0.7%).

Findings directly related to cystic echinococcosis were uncommon and included previous surgery for CE in 10 participants (0.7%) and suspected parasitic cystic lesions in 9 participants (0.6%).

These findings indicate that abdominal ultrasonography not only served as a screening tool for cystic echinococcosis but also identified a range of clinically relevant incidental abdominal abnormalities.

Figure 3. Representative abdominal ultrasonographic findings identified during community-based screening.



(A) **(B)**

(A) Gray-scale abdominal ultrasonography demonstrating a focal hepatobiliary abnormality identified during routine screening. The lesion was detected incidentally during systematic abdominal examination, with sonographic measurements of approximately 6.75 × 4.36 cm. The finding represents one of the hepatobiliary abnormalities recorded during the population-based survey.

(B) Color Doppler ultrasonography demonstrating a focal cystic-appearing hepatobiliary lesion measuring approximately 2.43 × 2.53 cm. Color Doppler imaging demonstrates the absence of internal vascular flow within the lesion, supporting its cystic nature. This image illustrates one of the incidental focal abnormalities encountered during community screening.

Table 3. Distribution of abdominal ultrasonographic findings among the study participants (N = 1,444)

Ultrasound finding	Number	Percentage
Normal	1,104	76.5
Hepatobiliary abnormality	165	11.4
Renal abnormality	97	6.7
Gallbladder disease	36	2.5
Pancreatic abnormality	10	0.7
Previous CE surgery	10	0.7
Reproductive system abnormality	10	0.7
Suspected parasitic lesion	9	0.6

Abbreviations: CE, cystic echinococcosis. Participants may have had more than one ultrasonographic abnormality; therefore, percentages may not total 100%.

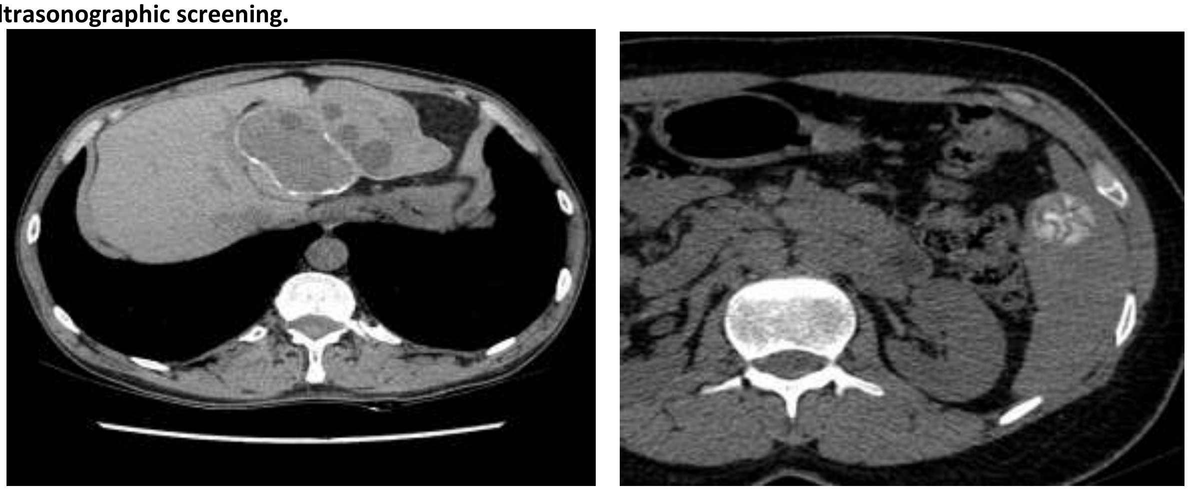
3.3.1. Confirmatory Computed Tomography Findings

In selected participants with ultrasonographic findings suspicious for cystic echinococcosis or complex cystic lesions, contrast-enhanced computed tomography (CT) was performed as a complementary imaging modality to improve diagnostic confidence and further characterize lesion morphology. CT was used as a confirmatory imaging technique following the initial ultrasonographic examination, particularly in cases where additional anatomical detail or differentiation from other cystic hepatic lesions was required.

Representative CT images are presented in Figure 4A**.** Figure 4 B demonstrates a well-defined cystic lesion within the liver containing peripheral curvilinear calcification, a radiological feature compatible with chronic cystic echinococcosis**.** Figure 4B illustrates a smaller hepatic cystic lesion identified on axial CT imaging, providing additional anatomical characterization following the initial ultrasound examination.

The combined use of abdominal ultrasonography as the primary screening modality and CT as a confirmatory imaging technique increased diagnostic confidence in selected cases and facilitated more accurate characterization of suspected echinococcal lesions.

Figure 4. Representative contrast-enhanced computed tomography (CT) findings obtained in selected participants following ultrasonographic screening.



(A) **(B)**

(A) Axial CT image demonstrating a well-circumscribed hepatic cystic lesion with peripheral curvilinear calcification, consistent with imaging features suggestive of chronic cystic echinococcosis.

(B) Axial CT image demonstrating a smaller focal hepatic cystic lesion identified during confirmatory evaluation after ultrasonographic detection. CT imaging provided additional anatomical information and increased diagnostic confidence in selected participants with suspected cystic echinococcosis.

3.4. Univariable Analysis of Factors Associated with Seropositivity

The association between demographic, environmental, and behavioral characteristics and anti-Echinococcus granulosus IgG seropositivity was initially evaluated using univariable logistic regression. Crude odds ratios (ORs) with 95% confidence intervals (95% CIs) were calculated for each candidate predictor. Variables with a P value <0.20 or considered biologically relevant were considered for inclusion in the multivariable model.

Sex was not significantly associated with seropositivity (OR = 0.87, 95% CI 0.57–1.31, P = 0.500). Similarly, household dog ownership was not associated with ELISA positivity (OR = 0.78, 95% CI 0.47–1.28, P = 0.325).

Participants from households reporting routine dog deworming had significantly lower odds of seropositivity than those from households without routine deworming (OR = 0.38, 95% CI 0.22–0.65, P < 0.001).

Feeding dogs raw livestock organs was not significantly associated with seropositivity (OR = 1.14, 95% CI 0.90–1.45, P = 0.282).

In contrast, the method used for disposal of infected animal organs demonstrated a statistically significant association with ELISA positivity (OR = 0.69, 95% CI 0.56–0.86, P = 0.001), suggesting that safer disposal practices may reduce the likelihood of exposure to E. granulosus.

Neither the source of household drinking water nor a history of abdominal ultrasonography during the preceding two years showed statistically significant associations with serological positivity.

Table 4. Univariable logistic regression analysis of factors associated with anti-Echinococcus granulosus IgG seropositivity

Variable	Crude OR	95% CI	P value
Sex	0.87	0.57–1.31	0.500
Dog ownership	0.78	0.47–1.28	0.325
Routine dog deworming	0.38	0.22–0.65	<0.001
Feeding dogs raw offal	1.14	0.90–1.45	0.282
Disposal of infected organs	0.69	0.56–0.86	0.001
Drinking water from household tap	1.29	0.61–2.71	0.506
River water	0.52	0.19–1.46	0.215
Street tap water	1.15	0.41–3.29	0.788
Previous abdominal ultrasonography	0.78	0.53–1.15	0.216

Abbreviations: OR, odds ratio; CI, confidence interval. Odds ratios and corresponding 95% confidence intervals were estimated using univariable logistic regression. Variables with P < 0.20 in the univariable analysis were considered for inclusion in the multivariable logistic regression model.

3.5. Multivariable Logistic Regression Analysis

Variables with a P-value < 0.20 in the univariable analysis, together with variables considered epidemiologically relevant based on previous evidence, were entered simultaneously into a multivariable logistic regression model using the enter method. Participants with equivocal ELISA results (n = 20) were excluded from the regression analysis, leaving 1,424 participants for the final model. Adjusted odds ratios (aORs) and corresponding 95% confidence intervals (95% CIs) were calculated.

After adjustment for potential confounding factors, routine dog deworming remained the only statistically significant independent predictor of anti-Echinococcus granulosus IgG seropositivity. Participants reporting routine dog deworming had approximately 2.30-fold higher odds of seropositivity compared with the reference category (aOR = 2.30, 95% CI 1.23–4.31; P = 0.009).

No statistically significant independent associations were observed for age (aOR = 1.00 per one-year increase, 95% CI 0.99–1.01; P = 0.635), sex (aOR = 1.15, 95% CI 0.74–1.77; P = 0.534), household dog ownership (aOR = 1.08, 95% CI 0.61–1.92; P = 0.785), feeding dogs raw livestock organs (aOR = 0.68, 95% CI 0.20–2.28; P = 0.527), disposal practices for infected animal organs, or household water source (Table 5).

Notably, the association between routine dog deworming and seropositivity differed from that observed in the univariable analysis, in which routine dog deworming appeared to be associated with lower odds of seropositivity. This reversal following multivariable adjustment should therefore be interpreted with caution, as it may reflect residual confounding, differences in exposure patterns, reverse causation, or other unmeasured factors rather than a direct causal relationship.

The overall multivariable logistic regression model demonstrated a statistically significant improvement over the null model (Likelihood Ratio χ^2 test, $P < 0.001$), indicating that the included predictors collectively contributed to explaining variation in anti-Echinococcus granulosus IgG serological status.

Model diagnostics. Multicollinearity among the independent variables was assessed using the variance inflation factor (VIF). Most explanatory variables demonstrated low levels of multicollinearity (VIF<4), indicating acceptable independence among predictors. Household dog ownership exhibited a higher VIF (17.03), reflecting its close correlation with other dog-related variables included in the model. Overall, the remaining predictors did not demonstrate problematic multicollinearity. Model calibration was assessed using the Hosmer–Lemeshow goodness-of-fit test, which demonstrated excellent agreement between observed and predicted outcomes ($\chi^2 = 2.11$, $P = 0.977$). Model discrimination was evaluated using receiver operating characteristic (ROC) analysis. The final multivariable logistic regression model achieved an area under the ROC curve (AUC) of 0.652, indicating acceptable discrimination between seropositive and seronegative participants.

Table 5. Multivariable logistic regression analysis of factors independently associated with seropositivity for cystic echinococcosis among study participants (N = 1,424).

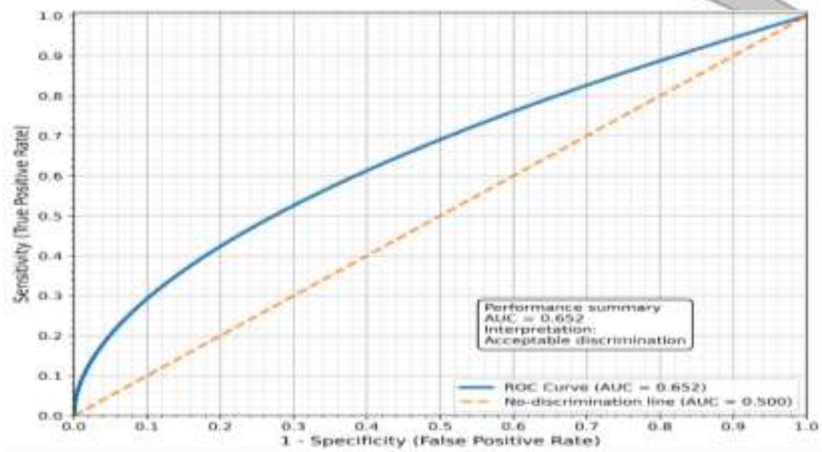
Variable	Adjusted OR (aOR)	95% CI	P value
Age (per year)	1.00	0.99–1.01	0.635
Female sex	1.15	0.74–1.77	0.534
Household dog ownership	1.08	0.61–1.92	0.785
Routine dog deworming	**2.30**	**1.23–4.31**	**0.009**
Feeding dogs raw offal	0.68	0.20–2.28	0.527
Disposal of infected organs (Category 2 vs 1)	1.72	0.80–3.70	0.164
Disposal of infected organs (Category 3 vs 1)	0.83	0.39–1.75	0.617
Disposal of infected organs (Category 4 vs 1)	0.54	0.22–1.28	0.160
Household water source	1.16	0.54–2.48	0.698

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval. The multivariable logistic regression model included variables with P < 0.20 in the univariable analysis together with epidemiologically relevant variables identified a priori.

Variable	**VIF**
Age	1.09
Female sex	1.07
Household dog ownership	17.03
Routine dog deworming	1.07
Feeding dogs raw livestock organs	1.04
Disposal of infected organs	2.89–3.65
Household water source	1.02–1.04

Supplementary Table S1. Assessment of multicollinearity.

Figure S1. Receiver Operating Characteristic (ROC) Curve of the Final Multivariable Logistic Regression Model.



4. Discussion

4.1. Principal Findings

The present population-based cross-sectional study provides one of the most comprehensive recent assessments of human cystic echinococcosis (CE) in southern Kyrgyzstan by integrating epidemiological questionnaires, abdominal ultrasonography, and serological testing in a large community sample of 1,444 participants. An overall seroprevalence of 7.9% was observed, indicating continued exposure of the study population to Echinococcus granulosus. Approximately one in thirteen participants demonstrated serological evidence of exposure, suggesting ongoing transmission within the community. The combined use of serological testing, abdominal ultrasonography, and detailed epidemiological data provided a comprehensive assessment of both the burden of infection and its associated risk factors. A major strength of the present study is the integration of complementary diagnostic and epidemiological approaches within a population-based survey, allowing a more comprehensive evaluation than studies relying on a single diagnostic modality. Together, these findings indicate that cystic echinococcosis remains an important public health challenge in southern Kyrgyzstan and underscore the need for sustained surveillance, strengthened veterinary and public health interventions, and integrated One Health control strategies to reduce disease transmission [1–5].

In the multivariable logistic regression model, routine dog deworming was the only variable independently associated with ELISA seropositivity, whereas age, sex, household dog ownership, feeding dogs raw livestock organs, household water source, and disposal practices for infected animal organs were not independently associated with seropositivity after adjustment for potential confounding variables. Notably, the direction of the association for routine dog deworming differed between the univariable and multivariable analyses. This unexpected finding should therefore be interpreted cautiously, as it may reflect residual confounding, reverse causation, differences in exposure patterns, or other unmeasured factors rather than a direct causal relationship. Overall, these findings suggest that the transmission dynamics of CE are considerably more complex than simple household-level exposures and are influenced by environmental contamination, livestock husbandry practices, free-roaming dog populations, and broader ecological factors operating at the community level [2, 4, 6].

The observed seroprevalence reflects immunological exposure to E. granulosus rather than the presence of active cystic disease and therefore should not be interpreted as evidence of viable hepatic or pulmonary cysts in every seropositive individual. Consequently, combining serological screening with abdominal ultrasonography remains the preferred strategy for population-based epidemiological surveys, particularly in endemic regions where asymptomatic infections are common, as the two methods provide complementary information regarding both exposure and active disease [1, 3, 7].

4.2. Comparison with Previous Studies

The seroprevalence observed in the present study is consistent with reports from several endemic regions where community-based surveys have documented substantial human exposure to Echinococcus species. Previous investigations conducted in western China, eastern Turkey, Iran, Peru, Argentina, and North Africa have reported seroprevalence estimates generally ranging from 3% to 13%, depending on the diagnostic assay employed, the demographic characteristics of the study population, and the local intensity of parasite transmission [3, 5, 8–12]. The prevalence identified in the present study therefore places southern Kyrgyzstan among the moderately to highly endemic regions for cystic echinococcosis worldwide.

Central Asia remains one of the world's recognized hotspots for cystic echinococcosis. Following the dissolution of the Soviet Union, deterioration of veterinary infrastructure, reduced slaughterhouse inspection, increasing populations of free-roaming dogs, and substantial changes in livestock production systems contributed to increased transmission across several countries, including Kyrgyzstan, Kazakhstan, Tajikistan, and Uzbekistan [13–16]. Although numerous hospital-based studies have documented increasing surgical incidence of CE in Kyrgyzstan during the past three decades, relatively few population-based investigations have evaluated asymptomatic infection using combined serological and ultrasonographic screening. Consequently, the present study provides valuable epidemiological evidence that complements national hospital surveillance data and contributes to a more comprehensive understanding of the community burden of infection.

The proportion of ultrasonographic abnormalities identified in this study should not be interpreted as representing the prevalence of cystic echinococcosis itself. Similar community-based investigations have demonstrated that abdominal ultrasonography detects a broad spectrum of incidental hepatobiliary, renal, pancreatic, gynecological, and other abdominal abnormalities in addition to hydatid cysts. Nevertheless, ultrasonography remains the imaging modality of choice for community screening because of its safety, portability, relatively low cost, absence of ionizing radiation, and excellent diagnostic performance for hepatic cystic echinococcosis [1, 4]. When used together with serological testing, ultrasonography provides a more comprehensive assessment of both exposure and clinically detectable disease than either diagnostic approach alone.

4.3. Interpretation of Risk Factors

Contrary to expectations, household dog ownership was not independently associated with anti-Echinococcus granulosus IgG seropositivity after adjustment for potential confounding factors. Similar observations have been reported in several endemic settings where environmental contamination with Echinococcus eggs is widespread and exposure may occur through contaminated soil, water, vegetables, or contact with free-roaming community dogs rather than exclusively through ownership of household dogs [9, 11]. Consequently, household dog ownership alone may represent an insufficient indicator of cumulative exposure risk in highly endemic communities.

Likewise, feeding dogs raw livestock organs was not independently associated with seropositivity in the multivariable analysis. Although this practice is widely recognized as an important mechanism for maintaining the life cycle of E. granulosus, its epidemiological effect may be difficult to detect in cross-sectional studies because of reporting bias, variability in slaughtering practices, misclassification of exposure, or the concurrent implementation of other preventive measures. Similar findings have been reported in studies from China and South America, suggesting that human infection risk is determined by multiple interacting environmental, behavioral, and ecological factors rather than any single exposure [8, 10].

The positive association observed between routine dog deworming and seropositivity requires particularly cautious interpretation. From a biological perspective, regular praziquantel treatment of dogs is expected to reduce canine infection and consequently decrease environmental contamination with E. granulosus eggs. Therefore, the observed association is unlikely to represent a direct causal relationship. Several explanations may account for this finding. First, households living in areas with historically higher transmission may be more likely to implement routine dog deworming because of previous experience with cystic echinococcosis or increased awareness of the disease, resulting in reverse causation. Second, the possibility of exposure misclassification or reverse coding of questionnaire responses should be carefully considered. Third, residual confounding by unmeasured environmental, behavioral, or socioeconomic factors cannot be excluded. Similar unexpected associations have occasionally been reported in observational studies evaluating preventive behaviors, in which interventions are preferentially adopted by populations already at elevated baseline risk [17–19]. Consequently, this finding should be interpreted with caution and should not be considered evidence that routine canine deworming increases the risk of human infection. On the contrary, regular praziquantel treatment of dogs remains one of the cornerstones of international cystic echinococcosis control programmes and is strongly recommended by the World Health Organization and other international authorities [4, 19, 20].

4.4. Public Health Implications

The findings of the present study reinforce the need for integrated One Health approaches that simultaneously address the human, animal, and environmental components of cystic echinococcosis transmission. Sustainable disease control requires close collaboration among veterinary services, public health authorities, livestock producers, and local communities. Key interventions include regular praziquantel treatment of owned dogs, effective meat inspection, safe disposal of infected livestock offal, restriction of dog access to slaughter waste, improved management of free-roaming dog populations, and continuous community-based health education to reduce environmental contamination and interrupt parasite transmission [4, 19].

Because cystic echinococcosis frequently remains asymptomatic for many years, periodic abdominal ultrasonography in highly endemic rural communities may facilitate earlier detection of clinically significant disease, improve patient management, and reduce disease-related morbidity. The World Health Organization Informal Working Group on Echinococcosis (WHO-IWGE) recommends ultrasound-based surveillance as an essential component of epidemiological monitoring and evaluation of control programmes, particularly in endemic settings where access to advanced imaging modalities may be limited [1, 4, 21].

The continued evidence of human exposure observed in southern Kyrgyzstan also highlights the importance of strengthening national surveillance systems, improving coordination between the medical and veterinary sectors, and implementing evidence-based prevention strategies tailored to local epidemiological conditions. Continued monitoring through population-based surveys will be important for evaluating the long-term effectiveness of control interventions and guiding future public health policy.

4.5. Strengths of the Study

This study has several important strengths. First, it included a relatively large population-based sample of 1,444 participants, providing adequate statistical power for epidemiological analyses. Second, the combined use of standardized epidemiological questionnaires, abdominal ultrasonography, and ELISA-based serological testing enabled a comprehensive assessment of both exposure to E. granulosus and potential disease burden. Third, the population-based sampling strategy minimized the selection bias commonly encountered in hospital-based studies and permitted the evaluation of both symptomatic and asymptomatic individuals within the community. Finally, this study provides important contemporary epidemiological data from southern Kyrgyzstan, a region where large community-based investigations remain limited despite the well-recognized endemicity of cystic echinococcosis. These findings contribute valuable evidence to support future surveillance activities and the development of targeted control strategies in Central Asia.

4.6. Limitations

Several limitations of this study should be acknowledged. First, the cross-sectional study design precludes establishing temporal or causal relationships between the investigated risk factors and anti-Echinococcus granulosus IgG seropositivity. Second, questionnaire-based data may have been affected by recall bias and social desirability bias, potentially influencing the accuracy of self-reported exposures. Third, ELISA detects immunological exposure rather than active infection and may produce both false-positive and false-negative results; therefore, serological findings should be interpreted in conjunction with abdominal ultrasonography and clinical assessment whenever possible. Fourth, several environmental and behavioral variables were self-reported and may not fully reflect cumulative lifetime exposure to Echinococcus eggs. Finally, molecular characterization of Echinococcus species or genotypes was not performed, preventing assessment of circulating strains and transmission patterns within the study area.

5. Conclusions

This population-based cross-sectional study provides robust epidemiological evidence that human cystic echinococcosis (CE) remains an important public health concern in southern Kyrgyzstan. The observed seroprevalence of 7.9% indicates continued community exposure to Echinococcus granulosus and suggests ongoing transmission within this endemic setting. By integrating standardized epidemiological questionnaires, ELISA-based serological testing, and abdominal ultrasonography in a large community-based sample, this study provides a comprehensive assessment of both infection exposure and disease burden, contributing valuable baseline epidemiological data for CE surveillance and control in Central Asia.

Multivariable logistic regression identified routine dog deworming as the only variable independently associated with ELISA seropositivity after adjustment for potential confounding factors. Because the direction of this association differed from that observed in the univariable analysis and was contrary to established biological expectations, the finding should be interpreted with caution. The observed association may reflect residual confounding, reverse causation, exposure misclassification, or other unmeasured factors rather than a direct causal relationship. Importantly, this finding should not be interpreted as evidence against routine canine deworming, which remains one of the most effective and internationally recommended interventions for the prevention and control of cystic echinococcosis.

No independent associations were observed for age, sex, household dog ownership, feeding dogs raw livestock organs, household water source, or disposal practices for infected animal organs after multivariable adjustment, suggesting that human exposure in this endemic region is likely driven by complex environmental and community-level transmission dynamics rather than isolated household-level risk factors.

The findings of this study have important implications for public health policy and disease control in Kyrgyzstan. They support the implementation and long-term strengthening of integrated One Health strategies that simultaneously address the human, animal, and environmental components of parasite transmission. Sustainable control of cystic echinococcosis will require coordinated multidisciplinary interventions, including regular praziquantel treatment of dogs, effective management of free-roaming dog populations, strengthened veterinary surveillance, rigorous meat inspection, safe disposal of infected livestock offal, improved slaughterhouse practices, community-based health education, and periodic abdominal ultrasonography in highly endemic communities. Such integrated approaches are essential for interrupting the parasite life cycle and reducing the long-term burden of disease.

Beyond its immediate public health relevance, this study provides important contemporary epidemiological evidence from southern Kyrgyzstan, where high-quality community-based data remain limited despite the recognized endemicity of cystic echinococcosis. The findings provide a valuable foundation for future surveillance programmes and for evaluating the long-term impact of national control strategies.

Future research should prioritize prospective longitudinal cohort studies, molecular characterization of circulating Echinococcus genotypes, geospatial mapping of transmission hotspots, and integrated human–animal surveillance systems to better define transmission pathways and identify modifiable risk factors. Such evidence will be essential for developing targeted, evidence-based control programmes and for supporting the World Health Organization's efforts to reduce the global burden of neglected tropical diseases through sustainable One Health interventions.

Declarations

Ethics Approval and Consent to Participate

The study was conducted in accordance with the principles of the Declaration of Helsinki and applicable national regulatory requirements governing biomedical research. The study protocol was approved by the Ethics Committee of the Research and Production Association "Preventive Medicine" of the Ministry of Health of the Kyrgyz Republic (extract from Protocol No. 1 dated February 19, 2010). Prior to enrollment, all participants were informed about the objectives and procedures of the study, and participation was voluntary. The survey was conducted anonymously; no personal data or information that could identify participants were collected. Written informed consent was obtained from all adult participants before their inclusion in the study. For participants under 18 years of age, informed consent was obtained from their parents or legal guardians.

Availability of Data and Materials

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. Data are not publicly available because they contain potentially identifiable participant information and are subject to institutional ethical restrictions.

Competing Interests

The authors declare that they have no competing interests.

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Abbreviations

Abbreviation	Definition
CE	Cystic echinococcosis
WHO	World Health Organization
WHO-IWGE	WHO Informal Working Group on Echinococcosis
ELISA	Enzyme-linked immunosorbent assay
OR	Odds ratio
aOR	Adjusted odds ratio
CI	Confidence interval
SD	Standard deviation
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology

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