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Ecological study of human brucellosis in Iran from 2000 to 2023 and the limited role of climatic factors

Marziyeh Hamyali-Ainvand[1], Owrang Eilami[2], Aboozar Soltani[3] & Kourosh Azizi[3✉]

Human brucellosis remains a major public health issue in endemic regions such as Iran. While climatic variables may affect transmission patterns, their role remains uncertain. This study analyzed long-term trends of human brucellosis in relation to climatic factors in Iran from 2000 to 2023. A time-series ecological design was applied using annual crude incidence rates (CIR) of brucellosis alongside climatic indicators including annual mean temperature (AMT), annual precipitation (AP), and the Standardized Precipitation Evapotranspiration Index (SPEI). Correlation tests, linear regressions, and multivariate models were performed. The average CIR was 23.96 per 100,000. AMT showed an inverse correlation with CIR, while SPEI indicated a weak positive association. Precipitation was not significantly correlated. Multivariate models explained less than one-quarter of variance, and no climatic factor remained a significant predictor. Findings suggest that climatic variables alone have limited explanatory power for brucellosis trends in Iran, with socioeconomic, agricultural, and behavioral factors likely playing a much greater role. Rather than demonstrating a strong climate–disease link, this study highlights the complexity and potential insignificance of climatic influence on brucellosis incidence, underscoring the need for integrated One Health approaches.

Brucellosis, a bacterial zoonotic disease, is recognized by the World Health Organization (WHO) as one of the neglected tropical diseases. Despite its high prevalence in developing countries, it receives insufficient attention for prevention and control[1]. This disease has been reported in at least 170 countries, with its geographic scope expanding significantly due to global trade, increased human-animal interactions, and climate change[2–4].

From a One Health perspective, which emphasizes the interconnectedness of human, animal, and environmental health, brucellosis exemplifies how zoonoses are influenced by multifaceted factors[5]. Primarily caused by *Brucella melitensis*, *Brucella abortus*, and *Brucella suis*, human brucellosis is transmitted via unpasteurized dairy products or direct contact with infected animal tissues[6–10]. Socio-economic determinants, such as rural lifestyles, poverty, and traditional consumption habits, exacerbate transmission, particularly among high-risk groups like herders, slaughterhouse workers, veterinarians, men, the elderly, and rural children due to occupational exposure, weakened immunity, and dietary practices[11–14].

This disease presents with flu-like symptoms including fever, fatigue, and sweating, and in chronic cases can lead to complications such as arthritis or myocarditis[9,15]. Epidemiologically, incidence is shaped by environmental factors (e.g., temperature, humidity, and precipitation) and socio-economic conditions (e.g., rural living and unpasteurized dairy consumption), often with a 2- to 4-month lag in human cases[6,16,17].

Climate change further amplifies these risks by altering environmental variables like temperature, precipitation, and humidity, thereby modifying transmission patterns[6,17–20]. In endemic regions, integrating climate data with socio-economic and One Health frameworks is crucial for effective disease management[5,21].

In Iran, brucellosis poses a significant public health challenge, especially in rural areas, with incidence rates ranging from 0.03 to over 200 cases per 100,000 population[22–24]. Prior studies indicate associations with

[1]Student Research Committee, Shiraz University of Medical Sciences, Shiraz, Iran. [2]Department of Infectious Diseases and Family Medicine, Shiraz University of Medical Sciences, Shiraz, Iran. [3]Research Center for Health Sciences, Institute of Health, Department of Medical Entomology and Vector Control, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran. ✉email: azizik@sums.ac.ir

climatic factors like reduced precipitation and moderate wind speed, though temperature effects are weaker[25,26]. These insights highlight the need for combined epidemiological and climate models to improve prediction and control[18,27].

This study analyzes trends in the crude incidence rates (CIR) of human brucellosis in Iran from 2000 to 2023 and examines associations with climatic variables, including annual mean temperature (AMT), annual precipitation (AP), and the Standardized Precipitation Evapotranspiration Index (SPEI). By incorporating a One Health lens and exploring both significant and non-significant associations, the findings aim to clarify the role of climatic factors while highlighting non-climatic drivers—such as socio-economic influences—and inform preventive policies and climate-informed forecasting models.

Methods
This time-series ecological study was conducted to investigate the relationship between climatic variables and the incidence of human brucellosis in Iran over the period from 2000 to 2023.

Data sources
Annual data on the number of confirmed human brucellosis cases were obtained from official reports issued by the Iranian Ministry of Health and Medical Education for the years 2000 to 2023. These surveillance data cover the entire country and are compiled through the national portal of the Center for Communicable Diseases Management (ICDC) of the Ministry's Deputy of Public Health (see Supplementary File S1: Brucellosis Data Source, Ministry of Health, Iran [in Persian])[28]. Data on climatic variables—including annual mean temperature (AMT), annual precipitation (AP), and the Standardized Precipitation Evapotranspiration Index (SPEI)—were extracted from the Iran Climate Status Booklet, published in 2023 by the Iran Meteorological Organization, covering the same study period from 2000 to 2023 (see Supplementary File S2: Climate Status Report, Iran Meteorological Organization [in Persian, with English summary])[29]. Please note that the referenced source is in the Persian language.

Incidence rate calculation
The annual crude incidence rate (CIR) of human brucellosis was calculated by dividing the number of confirmed cases by the annual population of Iran—obtained from the World Health Organization database—and multiplying the result by 100,000[30].

Statistical analysis
Normality of the data distribution was assessed using the Shapiro–Wilk and Kolmogorov–Smirnov tests. Non-normally distributed variables and those containing negative values were normalized through logarithmic transformation. Statistical analyses were conducted in three steps:

(1) *Correlation analysis* The initial associations between climatic variables (temperature, precipitation, and SPEI) and the crude incidence rate (CIR) of brucellosis were evaluated using Pearson's correlation test for normally distributed data and Spearman's rank correlation for non-normal data.
(2) *Simple linear regression* The individual effect of each climatic variable on CIR was examined using simple linear regression models.
(3) *Multivariate regression* The simultaneous effects of climatic variables on CIR were analyzed using multiple regression models, with adjustments for potential confounding variables. Multicollinearity was assessed using variance inflation factors (VIF) and tolerance values. Given the high correlation between annual precipitation (AP) and SPEI, additional regression models excluding AP were performed to evaluate the robustness of associations.

All statistical analyses were performed using SPSS software version 26 (IBM SPSS Statistics for Windows, Version 26.0), and a p-value of less than 0.05 was considered statistically significant[31].

Data quality control
To minimize bias, both climatic and epidemiological data were sourced from reputable and reliable databases. Prior to analysis, the data underwent a thorough review and cleaning process to ensure their accuracy and validity.

Results
In the present study, the annual average crude incidence rate (CIR) of human brucellosis in Iran was 23.96 per 100,000 individuals (23.96 ± 5.75), with values fluctuating between 16.2 and 37.2 during the study period. The annual mean precipitation was 206.71 mm (standard deviation: 44.85), and the annual mean temperature was 18.17 °C (18.17 ± 0.50), ranging from a minimum of 17.2 °C to a maximum of 19.2 °C over the years studied. The Standardized Precipitation Evapotranspiration Index (SPEI) had an average value of -0.79 (± 0.62), with fluctuations between a minimum of -1.58 and a maximum of 0.75 (Table 1). Trends in CIR, AMT, AP, and SPEI are shown in Fig. 1 (panels a–d).

Correlation results
Pearson correlation showed a significant negative association between CIR and AMT ($r = -0.439$, $p = 0.032$). CIR–AP correlation was positive but not significant ($r = 0.237$, $p = 0.265$). Spearman's rho between CIR and SPEI was $\rho = 0.408$ ($p = 0.048$). AMT was negatively correlated with AP ($r = -0.332$, $p = 0.113$) and SPEI ($r = -0.365$, $p = 0.080$). A very strong positive correlation was observed between AP and SPEI ($r = 0.909$, $p < 0.001$) (Table 2).

Year	Iran Population	HB Number	CIR HB (per 100,000)	AP (mm/y)	AMT (°C)	SPEI
2000	65,544,383	15,022	22.9	147.1	17.7	0.75
2001	66,674,851	15,188	22.8	163.2	18.0	0.54
2002	67,327,117	16,471	24.5	196.3	18.5	0.15
2003	67,954,699	17,765	26.1	231.9	17.9	-0.26
2004	69,061,674	21,530	31.2	248.4	17.9	-0.33
2005	70,182,594	25,755	36.7	306.5	17.3	-0.3
2006	71,275,760	26,549	37.2	188.8	18.1	-0.55
2007	72,319,418	23,558	32.6	228.7	17.7	-0.63
2008	73,318,394	21,109	28.8	212	17.2	-0.8
2009	74,322,685	17,501	23.5	135.5	18.5	-0.91
2010	75,373,855	12,248	16.2	256.4	18.4	-0.86
2011	76,342,971	12,891	16.9	206.2	18.2	-0.86
2012	77,324,451	14,208	18.4	204	17.6	-0.89
2013	78,458,928	16,019	20.4	217.6	18.2	-0.95
2014	79,961,672	19,094	23.9	211	17.7	-1.12
2015	81,790,841	20,117	24.6	186.4	18.3	-1.19
2016	83,306,231	18,518	22.2	206.7	18.7	-1.22
2017	84,505,076	15,358	18.2	216.9	18.3	-1.34
2018	85,617,562	15,640	18.3	139.9	18.9	-1.27
2019	86,564,202	16,632	19.2	265.5	18.6	-1.27
2020	87,290,193	19,455	22.3	289.1	18.3	-1.26
2021	87,923,432	17,807	20.3	163.2	18.0	-1.36
2022	88,550,570	20,406	23.0	165.5	19.2	-1.44
2023	89,172,767	22,073	24.8	174.2	18.9	-1.58

Table 1. Distribution of the population, number of Human Brucellosis cases, Human Brucellosis crude incidence rate (CIR), Meteorogical parameters incloud Annual Mean Temperature (AMT) Annual Precipitation (AP) Standardized Precipitation Evapotranspiration Index (SPEI) in Iran for the period 2000–2023.
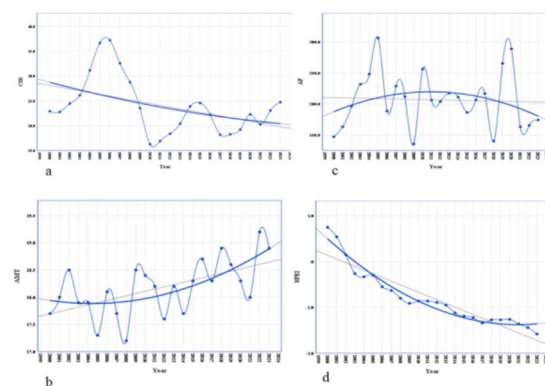

Fig. 1. (**a–d**) Trends of CIR and climatic variables in Iran, 2000–2023. (**a**) CIR trend, (**b**) AMT trend, (**c**) AP trend, (**d**) SPEI trend. The time series graph of the Standardized Precipitation Evapotranspiration Index (SPEI) from 2000 to 2023 demonstrates how climatic trends have influenced both drought and wet periods (**d**). This graph is presented without logarithmic transformation to preserve the actual temporal pattern of the drought index, allowing for a clearer understanding of the fluctuations in drought conditions over time.

Simple linear regression

Univariate regression analyses showed that AMT was a significant predictor of CIR (B = −5.021; p = 0.032; R^2 = 0.193), whereas AP exhibited a positive but non-significant association (B = 0.030; p = 0.265; R^2 = 0.056). Similarly, the log-transformed SPEI (SPEI_log) demonstrated a positive, though non-significant, relationship with CIR (B = 8.092; p = 0.081; R^2 = 0.132). Detailed coefficients for these simple models are provided in Supplementary Table S1, and corresponding scatterplots are illustrated in Fig. 2 (panels a–c).

Correlations		CIR	AMT	AP	SPEI
CIR	Pearson Correlation	1	− 0.439*	0.237	0.185
	Sig. (2-tailed)		0.032	0.265	0.386
	N	24	24	24	24
AMT	Pearson Correlation	− 0.439*	1	− 0.332	− 0.365
	Sig. (2-tailed)	0.032		0.113	0.080
	N	24	24	24	24
AP	Pearson Correlation	0.237	− 0.332	1	0.909
	Sig. (2-tailed)	0.265	0.113		0.000
	N	24	24	24	24
SPEI	Spearman's Correlation	0.408*	− 0.365	0.909	1
	Sig. (2-tailed)	0.048	0.080	0.000	
	N	24	24	24	24

Table 2. Results of correlation analysis between crude incidence rate (CIR) of human brucellosis and climatic variables (AP, SPEI, AMT). Pearson correlation was used for normally distributed variables (CIR, AMT, AP). Spearman correlation was used for Raw SPEI due to its non-normal distribution. Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).
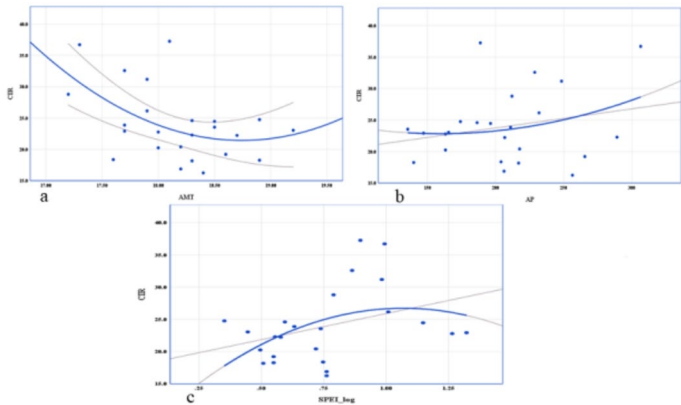

Fig. 2. (**a**–**c**) Scatter plots of climatic variables and CIR. (**a**) AMT vs. CIR, (**b**) AP vs. CIR, (**c**) SPEI vs. CIR.

Adjusted R Square	F	Significance (Sig.)
0.119	2.031	0.142

Table 3. Model summary for multiple linear regression analysis.

Multivariate regression results (Effect of AMT, AP, and SPEI_log on CIR)

Model summary and analysis of variance (ANOVA)
The multivariate regression model explains 23.4% of the variance in CIR, with an adjusted R^2 of 0.119. The F-statistic of the model is 2.031, and the p-value is 0.142, indicating that the model is not statistically significant at the 0.05 level (Table 3).

Regression coefficients
The multivariate regression analysis showed that SPEI_log had a positive standardized coefficient ($\beta = 0.213$, $p = 0.376$), AMT had a negative standardized coefficient ($\beta = -0.279$, $p = 0.278$), and AP had a positive standardized coefficient ($\beta = 0.141$, $p = 0.513$) (Table 4). Although temperature showed a significant effect in univariate models, the overall explanatory power of climatic variables was low. The multivariate model explained less than 25% of the variance and was not statistically significant.

When precipitation (AP) was excluded from the multivariate model to address collinearity with SPEI, the remaining predictors (AMT and SPEI_log) did not achieve statistical significance (AMT: $\beta = -0.343$, $p = 0.147$; SPEI_log: $\beta = 0.181$, $p = 0.435$). The model explained only 14.2% of the variance (adjusted R^2), and the overall model was not statistically significant (F = 2.902, $p = 0.077$). These findings confirm that multicollinearity did not

Independent variable	Standardized coefficient (Beta)	Significance level (Sig.)	95% confidence interval for B
(Constant)	–	0.203	[-43.623, 192.789]
SPEI_log	0.213	0.376	[-6.209, 15.718]
AP	0.141	0.513	[-0.039, 0.075]
AMT	-0.279	0.278	[-9.154, 2.772]

Table 4. Multiple regression coefficients: the effect of climatic variables on CIR.

mask any substantial climatic effect, and that climatic variables had limited explanatory power for brucellosis incidence.

Discussion

This ecological study of human brucellosis in Iran from 2000 to 2023 revealed an average annual incidence rate of 23.96 ± 5.75 per 100,000 population, with the lowest rate in 2010 (16.2 per 100,000) and the highest in 2006 (37.2 per 100,000). Univariate analyses showed a significant negative correlation between annual mean temperature (AMT) and incidence, while the Standardized Precipitation Evapotranspiration Index (SPEI) exhibited a significant positive correlation. However, none of the climatic variables— including annual precipitation—emerged as significant predictors in multivariate models, which explained less than 25% of the variance in incidence rates. These results underscore the limited and ambiguous influence of climatic factors on temporal trends in brucellosis.

Comparisons with prior studies

Our findings align with previous reports from Iran, where average incidence rates have ranged from 19.91 to 29.83 per 100,000 population[13,32,33]. The overall downward trend in incidence over the study period is consistent with studies documenting a decline from 26.83 per 100,000 in 2015 to 18.3 per 100,000 in 2020[32]. This reduction may stem from enhanced animal control programs, greater public awareness, and improved surveillance systems[22,34–37].

Factors influencing trends and incidence peaks

The observed downward trend could be driven by improvements in livestock management and public health measures. However, recent increases in incidence may reflect reduced adherence to preventive protocols, shifts toward small-scale non-industrial farming in urban and peri-urban areas post-COVID-19, antibiotic resistance, or heightened diagnostic sensitivity[25,38–40]. Peaks in incidence during 2006, 2015, 2020, and 2023 likely relate to non-climatic disruptions. In particular, the 2020 peak may be linked to COVID-19-related disruptions, including reduced zoonotic disease surveillance, altered food consumption patterns during lockdowns, and underreporting of infectious diseases overall. Studies indicate that the COVID-19 pandemic similarly affected reporting of diseases like tuberculosis and visceral leishmaniasis, suggesting parallel dynamics for brucellosis[41,42].

Moreover, the intrinsic epidemiological cyclicity of brucellosis plays a critical role in incidence fluctuations. This cycle involves animal reservoirs (e.g., cattle, sheep, goats), horizontal transmission via aborted fetuses or contaminated milk, environmental persistence of Brucella influenced by factors like temperature and humidity, and spillover to humans through direct contact or unpasteurized products. Periodic peaks may occur independently of climate trends, driven instead by epidemiological factors such as vertical transmission in animals or lapses in reservoir control[43,44].

Role of climatic factors

The negative correlation between AMT and brucellosis incidence is consistent with studies suggesting reduced Brucella survival at higher temperatures[16,18]. However, contrasting reports indicate that warmer temperatures in certain ranges may enhance bacterial metabolism and persistence[17,45]. The positive SPEI correlation implies indirect effects of drought, such as diminished vegetation leading to livestock congregation and heightened transmission risk[17,46]. Yet, discrepancies exist, with some Iranian studies showing inverse associations under quasi-drought conditions[16]. Precipitation results remain inconsistent, similar to other infectious diseases, where altered rainfall patterns have been linked to outbreaks of West Nile virus, diarrheal diseases, and waterborne infections[47–49]. Such parallels emphasize the need for nuanced investigations into indirect precipitation effects.

Overall, weak associations observed in simple regressions (e.g., AMT) did not persist in multivariate models, underscoring the limited explanatory power of climate alone. Strong multicollinearity between precipitation (AP) and SPEI was observed, so the analysis was repeated excluding AP; however, the associations remained non-significant, further indicating that climatic variables alone are insufficient to explain incidence trends.

Non-climatic drivers

Given the modest role of climate, socioeconomic, managerial, and behavioral factors likely dominate brucellosis epidemiology. Brucellosis disproportionately burdens low- and middle-income populations, such as farmers and herders, imposing economic strains through medical costs and livestock productivity losses. Rural and poorer areas face amplified challenges due to limited healthcare access, delayed care-seeking, and regional inequalities[50–52]. Effective control hinges on livestock management, including vaccination (e.g., RB51 for cattle, REV-1 for small ruminants), testing, culling infected animals, and surveillance[22,53,54]. Vaccination, while

cost-effective, requires integration with sanitation, farmer education, and infrastructure to succeed, though occupational risks (e.g., needle-stick injuries) persist and can be mitigated with protective measures.

Human behaviors—shaped by cultural, gender, and social norms—further influence transmission. For example, gender roles in animal care or dairy processing affect exposure, while practices like consuming unpasteurized milk stem from limited awareness or economic constraints[55,56]. Interventions should therefore prioritize culturally sensitive education and protective practices.

One health framework
These findings reinforce the relevance of a One Health approach, integrating human, animal, and environmental health. Cross-sector collaboration is essential to expand livestock vaccination, strengthen surveillance, and promote food safety awareness[5,21,57]. Incorporating socioeconomic and behavioral data into such frameworks can provide a more complete picture of disease dynamics and improve control strategies.

Study limitations
First, the use of annual, national-level data precluded analyses of regional, seasonal, or lagged effects. Second, important climatic indicators (e.g., relative humidity, wind speed, sunshine hours) were unavailable. Third, strong collinearity between precipitation and SPEI undermined the stability of multivariate models. Fourth, underreporting and evolving diagnostic practices—particularly during the COVID-19 pandemic—may have biased incidence estimates. Finally, socioeconomic and behavioral drivers were not analyzed, limiting a holistic understanding of brucellosis epidemiology.

Conclusions
Climatic variables such as temperature and drought show some correlation with brucellosis incidence, but their influence appears weak, inconsistent, and overshadowed by socioeconomic, health, and epidemiological factors. The main strength of this study lies in demonstrating the absence of a strong unidirectional link with climate. Rising temperatures may even hinder transmission, contributing to the overall downward trend. Effective control strategies in Iran should therefore emphasize livestock management, socioeconomic interventions, and culturally tailored community engagement within a One Health framework.

Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Author contributions

KA and MH designed and conceptualized the study. AS and OE gathered the data and MH and KA analyzed them. MH, KA, AS and OE drafted the manuscript. All the authors participated in writing the manuscript. All the authors have read and approved the final manuscript.

Declarations

Competing interests
The authors declare no competing interests.

Ethical approval
This study utilized officially published, aggregated data and did not involve human participants or the collection of personal data. Therefore, formal ethical approval was not required. Clinical trial number: not applicable.

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Correspondence and requests for materials should be addressed to K.A.

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