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Original Article

Risk Mapping and Spatial Modeling of Human Cystic Echinococcosis in Iran from 2009 to 2018: A GIS-Based Survey

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Abstract

Background: Cystic echinococcosis (CE) is one of the most important parasitic infections in subgroup seven common neglected diseases of humans and animals. It is in the list of 18 neglected tropical diseases of the WHO. We aimed to analyze the situation of the disease in Iran using Geographical Information System (GIS) and satellite data analysis.

Methods: The data obtained from the Ministry of Health and Medical Education, Tehran, Iran and other related centers from 2009 to 2018 were analyzed using GIS. Then, the spatial distribution maps of the disease were generated, and the hot spots of the disease in Iran were determined using spatial analysis of ArcGIS10.5 software. Geographically weighted regression (GWR) analysis in ArcGIS10.5 was used to correlate the variables affecting the disease including temperature, relative humidity, normalized different vegetation index (NDVI) and incidence of hydatidosis. Data analysis was performed by Linear regression analysis and SPSS 21 software using descriptive statistics and chi-square test.

Results: Zanjan, Khorasan Razavi, North Khorasan, Chaharmahal Bakhtiari, Hamedan, Semnan, and Ardabil provinces were the hot spots of CE. The results of geographical weighted regression analysis showed that in Khorasan Razavi, North Khorasan, Chaharmahal Bakhtiari, Hamedan, Semnan, Ardabil, Zanjan, Qazvin, and Ilam provinces, the highest correlation between temperature, humidity, vegetation density and the incidence of hydatidosis was observed ($P<0.001$).

Conclusion: The use of maps could provide reliable estimates of at-risk populations. Climatic factors of temperature, humidity, NDVI had a greater impact on the probability of hydatidosis. These factors can be an indicator used to predict the presence of disease. Environmental and climatic factors were associated with echinococcosis.

Introduction

Cystic echinococcosis or hydatidosis caused by *Echinococcus* sp. is one of the most important parasitic infections in the world. It is in the list of 18 neglected tropical diseases of the WHO (1, 2). In the evolutionary cycle of this parasite, domestic and wild carnivores, mainly dogs, are the final hosts. Herbivores and host humans are considered intermediate hosts of this parasite (3). This disease, which is responsible for approximately 1% of hospital admissions in Iran (2), is caused by the larval stages of *Echinococcus* cestodes and leads to significant economic losses due to medical treatment costs, complications, disease, and life disorders. In addition, the rate of human infection is 0.6-1.2 per 100,000 people (2).

Despite the establishment of control programs in a number of countries or indigenous regions, hydatidosis is still prevalent in a wide geographical area of the world (4). To date, a comprehensive program to control hydatidosis, which seems urgent and necessary, has not been implemented in Iran (2). Local studies are needed to better identify the risk factors for human infection, and in particular to evaluate the role of livestock breeding in the transmission of hydatidosis in high-risk provinces, as well as to implement a sustainable hydatidosis control program (2, 5-7).

In Iran, only spatial studies have focused on monomaterial studies or snail-borne helminths (8-10). Recently, studies have been conducted on the epidemiological causes and characteristics of hydatidosis in Iran. Due to the high number of human cases in the country, preparing a disease map using Geographic Information System (GIS) and analyzing satellite spatial data to identify the recurrence of the disease, modeling for reliable estimates of the population at risk, how dissemination and frequency of disease, clustering and distribution of parasite eggs in the environment, disease assessment, identification of high-risk and low-risk points, identification of endemic foci of the disease, identification of risk factors for hydatidosis are vital and part priorities are considered and its implementation in the current situation of the country is necessary for planning to control and reduce the burden of disease and the economy (6, 8, 9, 11-14).

We aimed to determine the incidence, spatial distribution, and hot spots of hydatidosis in Iran using the GIS during a decade from 2009 to 2018.

Methods

Data collection

Data related to CE in all provinces of Iran from 2009 to 2018 from the Ministry of Health (Disease Management Center), Tehran, Iran; published articles about the disease in the country, and in-person visits to some related centers in provincial centers were obtained. Searching for abstracts of conferences and dissertations were other sources of information that have been used.

The country's population information was obtained from the Statistics Center of Iran (15).

Meteorological information for a 10-year period from climatological stations in 31 provinces of the country for annual temperature and relative humidity during the years 2009 to 2018 was obtained from the National Meteorological Organization. The average annual temperature and relative humidity were calculated for the meteorological stations of the whole province, then the average of the total stations for each province was obtained, so that finally one temperature and one humidity value was obtained for each province and used for analysis. We used Google Earth Engine software to obtain the NDVI layer based on the border of Iran for the month of May in the years 2009 to 2018 at a spatial resolution of one square kilometer per pixel. These layers were clipped in ArcMap based on the borders of the provinces of the country and the average value of NDVI for different years in each province was calculated. The obtained numbers were used for geographical weighted regression in ArcMap10.5.

Data analysis

To calculate the incidence rate in 100000 people of the population of the provinces, the following formula was used:

Incidence rate = (new disease cases) / (risk in the population) × 100000

Spatial analysis

The spatial database of the disease including cases, age groups of patients, location, gender, mortality in different age groups was created in ArcMap. Then, spatial distribution maps of the disease were produced by the years of 2009-2018.

Using spatial analysis of ArcGIS10.5 software and Hot Spot Analysis tool, hot spots of the disease were determined in the provinces of Iran. Hot Spot Analysis in ArcGIS software is a tool for identifying provinces that are different significantly from other provinces in terms of the disease incidence. This disease-based database analysis calculates positive and negative numbers for Z-scores in each province. It shows which provinces are significantly the disease hotspots and which are cold spots. Statistically, the larger the positive value of Z-scores, the more critical the points and the more negative the value, the more non-critical points. In general, after performing the analysis, the points are divided into three categories of hot and cold points at three levels of confidence: 90%, 95% and 99%, and each has its own value of Z-value (16).

To investigate the relationship between environmental variables affecting the disease such as temperature, relative humidity, NDVI density and the incidence of hydatidosis during the years 2009 to 2018, spatial analysis of geographical weighted regression in ArcGIS10.5 was used. Geographically weighted regression (GWR) analysis was used to model spatially varying relationships between the incidence of hydatid cysts during the study period, as the dependent variable, and average annual temperature, average annual relative humidity and the NDVI as independent variables (17).

Statistical analysis of data was performed by Linear regression analysis and SPSS 21 software (Chicago, IL, USA) using descriptive statistics and chi-square test.

Results

During the studied years, 5315 cases of hydatidosis were registered in the country. The incidence rate of human hydatidosis is presented in Fig. 1.

During 10 years, the provinces of Zanjan, Chaharmahal Bakhtiari, Hamedan and Ardabil had the highest rate of bronchydatidosis (Fig. 2). The hot spots of the disease, i.e., the provinces of the highest rate of incidence of hydatidosis were Zanjan, Khorasan Razavi, Chaharmahal Bakhtiari, Hamedan, Semnan, North Khorasan and Ardabil (Fig. 2). Moreover, the results of GWR analysis showed that during these years, the highest correlation between humidity (Fig. 3), temperature (Fig. 4), and NDVI (Fig. 5) and the incidence of the disease was observed in the provinces of Zanjan, Khorasan Razavi, Chaharmahal Bakhtiari, Hamedan, Semnan, North Khorasan and Ardabil, Qazvin and Ilam.

Analysis of data showed that in 2018, the number of new cases of hydatidosis was 720 (318 males and 402 females). The overall incidence of hydatidosis was 0.9 per 100,000 patients (0.8 men and 0.99 women). According to these statistics, the highest incidence was in women in the age group of 65 to 70 years (2.5 per hundred thousand) and in men in the age group of 70 to 75 years (3 per hundred thousand). The lowest incidence was estimated in the age group less than 5 years (0.03 in men and 0.1 in women). Of the 720 new cases of hydatid cyst, 318 were seen in men and 402 in women.

The highest number of patients with hydatid cyst was observed in housewives during 2009-2018. With chi-square test, there was a significant difference between different job categories in different years in terms of the incidence of hydatid cyst (P= 0.001). During these years, the most hydatidosis infection was observed in urban areas.

Linear regression analysis was used to investigate the relationship between the incidence of hydatid cyst in 100,000 patients NDVI, relative humidity (RH) and mean temperature (TM) (Table1).

The results of the analysis showed that temperature and NDVI had a significant relationship with the incidence of hydatid cyst. On the other hand, increase of one degree Celsius temperature caused a decrease of 0.088 in the incidence of hydatid cyst (P<0.001). In addition, with the increase of each NDVI unit caused an increase of 1.543 in the incidence of the disease (P= 0.024) (Table 2).

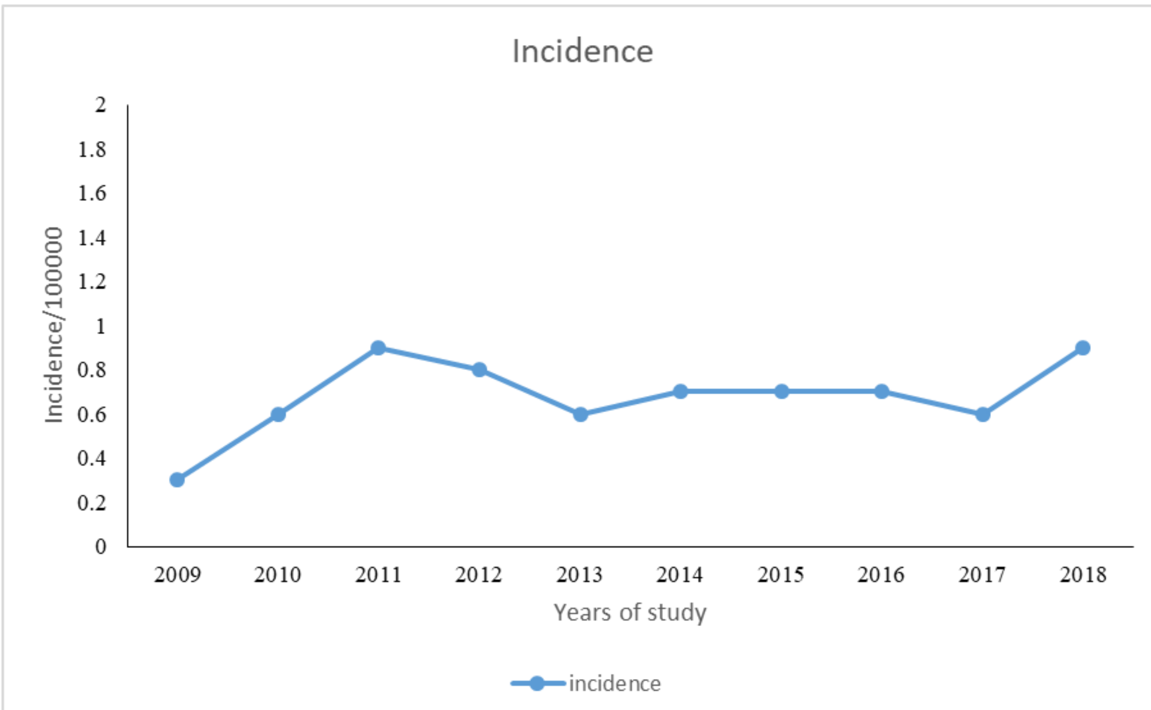

Fig. 1: The trend of human hydatidosis during the years 2009-2018 in Iran

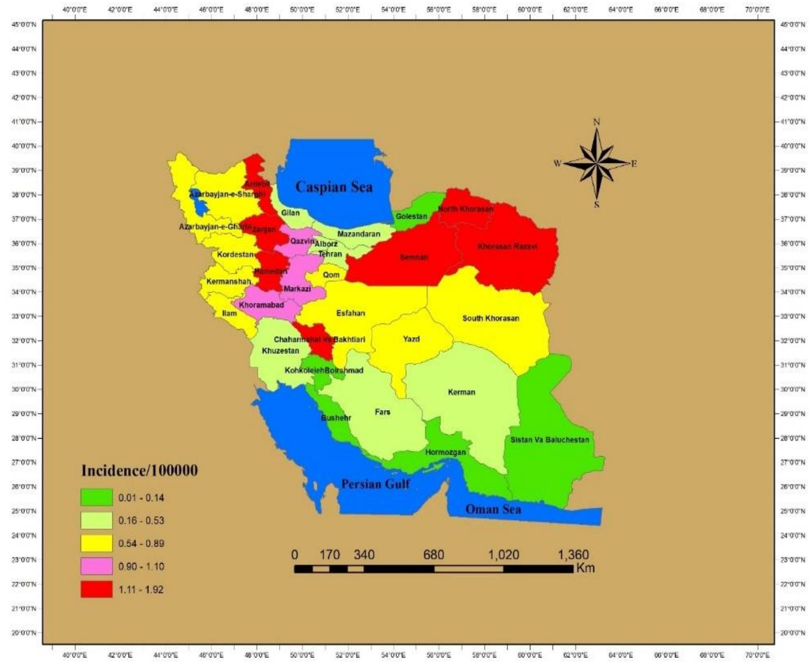

Fig. 2: The incidence of human hydatidosis in different provinces of Iran, 2009-2018

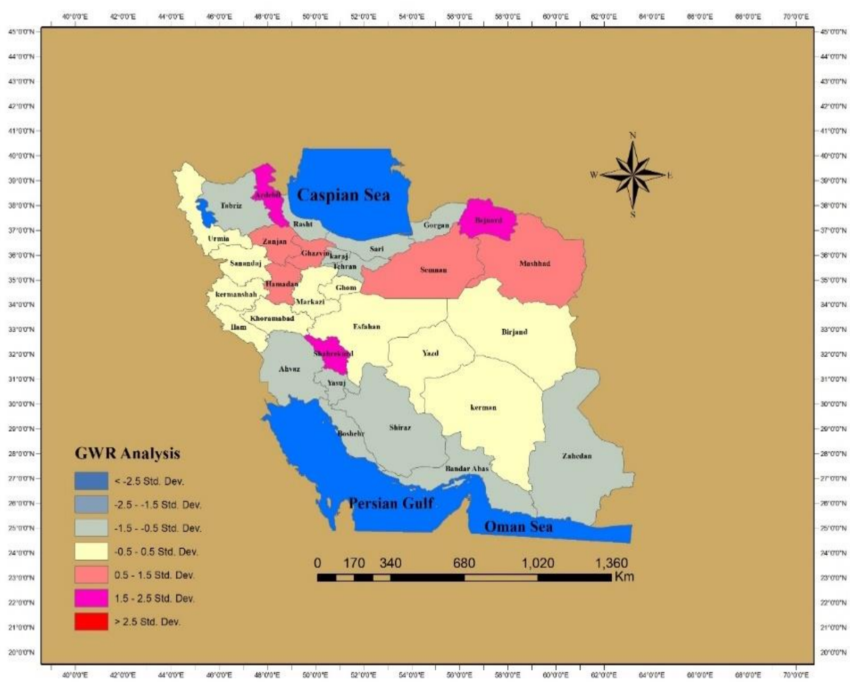

Fig. 3: The results of geographically weighted regression analysis of the correlation between the relative humidity and the incidence of human hydatidosis in Iran, 2009-2018

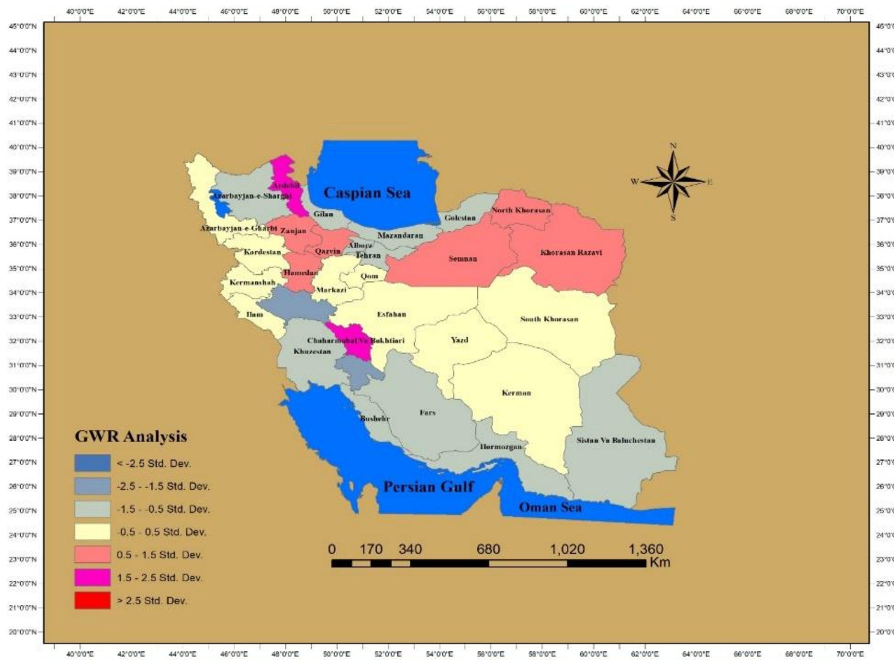

Fig. 4: The results of geographically weighted regression analysis of temperature correlation and incidence of human hydatidosis in Iran, 2009-2018

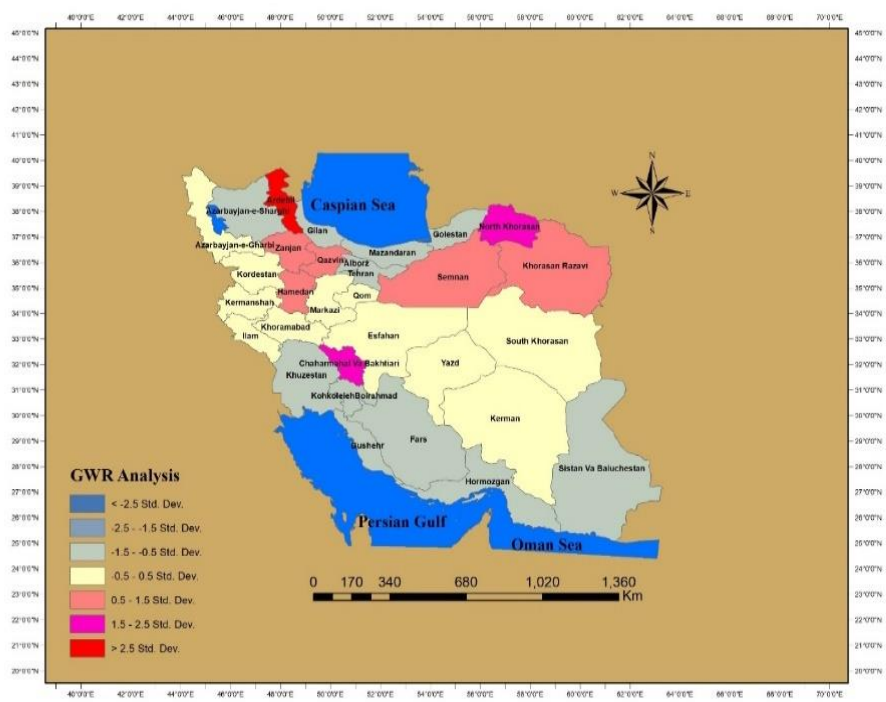

Fig. 5: The results of geographically weighted regression analysis of the correlation between NDVI and the incidence of human hydatidosis in Iran, 2009-2018

Table 1: Relationship between environmental variables and the incidence of hydatid cyst in Iran, 2009-2018

Province	*TM*	*RH*	*NDVI*	*Incidence/100000*
Alborz	16.40039214	30.82	0.294	0.4
Ardebil	9.268608143	62.83	0.409	1.92
Azarbayjan-e-Gharbi	13.45255068	52.31	0.423	0.839
Azarbayjan-e-Sharghi	12.74801269	45.94	0.356	0.6
Bushehr	25.58515797	57.25	0.096	0.029
Chaharmahal Va Bakhtiari	12.47099015	40.24	0.391	1.65
Esfahan	14.02026325	33.201	0.274	0.891
Fars	17.68660851	35.12	0.169	0.27
Gilan	15.83153861	69.54	0.556	0.243
Golestan	18.53809255	64.905	0.383	0.145
Hamedan	10.10541655	43.45	0.539	1.35
Hormozgan	24.68627044	56.35	0.075	0.011
Ilam	20.31200242	36.74	0.214	0.81
Kerman	24.0960181	28.56	0.139	0.526
Kermanshah	15.59402365	37.39	0.438	0.752
Khorasan Razavi	15.07798998	41.85	0.262	1.34
Khuzestan	25.06462137	39.57	0.146	0.248
Kordestan	12.84783848	43.17	0.468	0.866
Markazi	12.21402871	39.36	0.422	1.01
Mazandaran	16.21690237	68.35	0.447	0.306
North Khorasan	14.71020272	52.56	0.284	1.55
Qazvin	15.22403958	47.94	0.294	1.098
Qom	16.56578786	42.81	0.154	0.88
Semnan	15.29186281	33.9	0.322	1.45
Sistan Va Baluchestan	23.32389757	27.154	0.064	0.021
South Khorasan	18.50197443	30.28	0.162	0.78
Tehran	15.81778573	32.54	0.225	0.5
Yazd	17.43841887	26.12	0.124	0.76
Zanjan	12.75088759	49.15	0.442	1.4

TM: Mean annual temperature, RH: Average of annual relative humidity, NDVI: Normalized difference vegetation index

Table 2: Results of the univariate and multiple linear regression model

Variable	*Univariate*	
	Beta (SE)	*P*-value
TM	-0.088 (0.016)	<0.001
RH	-0.002 (0.008)	0.840
NDVI	1.543 (0.646)	0.024

TM: Temperature, RH: Humidity, NDVI: Normalized difference vegetation index

Discussion

In this study, hot foci of hydatid cyst were estimated using spatial analysis. During the years 2009-2018, cold foci of the disease, i.e. provinces in which the incidence of the disease was significantly low, were not observed. In addition, GWR was used to correlate the variables affecting the disease. The results of the present study are similar to a study in Tibet, China (18). Their results showed a significant relationship between the mean annual rainfall, altitude, access to water and animal population (dogs) with the prevalence of echinococcosis cysts. They used hot/cold point analysis and generalized collective regression model. Similar to our study, they used cold (statistically significantly low) and hot (statistically significantly high) point analysis to identify the disease clusters. They also used the generalized collective regression model as an important statistical model to discover potential links between the prevalence of echinococcosis and related variables (18).

According to the information available in the country, Khorasan Razavi Province ranked first in the country in terms of animal husbandry, followed by West, and East Azerbaijan (19, 20). North Khorasan (19) and Ardabil provinces are important centers of agriculture and animal husbandry (20, 21). Semnan Province has a good potential in terms of livestock due to its pastures (22). Chaharmahal Bakhtiari Province is one of the livestock centers of the country (22, 23). Zanjan Province is one of the centers of livestock production in the country. This province has a high potential in the field of livestock and agriculture development. This province has a variable climate situation so is apt to the best quality of agriculture (24, 25). Hamedan Province due to the diversity of climate, the existence of vast pastures and the region being appropriate for livestock and animal husbandry. Hamedan livestock is more traditional (26, 27). It seems that the development process of the livestock sector, in addition to the potential of climate, climate, human, infrastructure is also related to the factor of proximity to development centers (provincial and capital centers). Provinces with temperate climate, rainfall and good humidity have better conditions for establishing the life cycle of the parasite and the incidence of echinococcosis. Using geographical weight regression analysis, Zanjan, Khorasan Razavi, North Khorasan, Chaharmahal Bakhtiari, Hamadan, Semnan, Qazvin, Ilam and Ardabil have relative humidity, average annual temperature and good vegetation density, which create a very good potential for breeding and grazing, egg survival and proper parasite transmission cycle, contamination of intermediate and final hosts to parasites in these areas. As a result, the incidence of hydatidosis is higher in these areas (22, 28).

The severity of the disease is in areas with an average temperature between 10 and 20 degrees Celsius, i.e. in areas with an average temperature above 20 degrees Celsius, echinococcosis is rare and sometimes absent. Perhaps for this reason, hydatidosis is rare in the southern parts of Iran (29). The relationship between human cases of hydatid disease and the rate of livestock contamination was seen in some of these provinces. Large population of stray dogs, dependence of rural population on livestock breeding, feeding stray dogs, and consumption of vegetables contaminated with parasitic eggs due to dog contact with these summer pastures facilitate the transmission of hydatid cysts. Stray dogs infected with the parasite play a major role in the spread of the disease and increase its' prevalence in these areas (1). These infected stray dogs can easily spread large numbers of parasite eggs on farms where vegetables are grown. This is one of the most important factors in increasing the prevalence of the disease in intermediate hosts, including humans, in these areas. Human behavior in contact with dogs, which is closely related to the cultural and economic conditions of people, also plays an important role in the transmission of infection in humans (22).

In the present study, using geographically weighted regression analysis, the correlation between temperature, relative humidity, NDVI and the incidence of human hydatidosis was investigated. In Ilam, Semnan, Hamedan, Qazvin, and Ardabil provinces, the highest correlation was observed between temperature, relative humidity, and NDVI with the incidence of hydatidosis, which is similar to other studies (30-32). The results of Danson et al. study showed the application of GIS in the study of human parasitic infections is very useful and shows a better understanding of parasite transmission. It showed that environmental factors such as temperature, humidity and altitude have an effect on the distribution of worm infections (30), which is consistent with the results of our study.

In southwestern Iran, areas with less evaporation are the main areas of risk of *Echinococcus* cyst (31, 32). In our study, there was a correlation between the mean annual temperature, relative humidity, NDVI and the incidence of hydatidosis. The results of another study in Iran (32), showed a negative relationship between slope and echinococcosis cyst, while temperature, freezing days and latitude were not associated with echinococcosis cyst. The authors also reported the urban environment as the most important risk factor, probably due to a combination of the high density of life cycle hosts, dogs, and livestock, a large human population, and a large number of slaughterhouses. Cropland and moisture were other risk factors that increased the survival of *E. granulosus* eggs in the soil (32).

In our study, hydatid cyst infection was higher in the urban environment, which is similar to the results of another study (32). Besides, there was a correlation between the mean annual temperature, relative humidity, NDVI and the incidence of hydatidosis, but in previous study (32), temperature was not associated with the distribution of echinococcosis cyst and the urban environment, dogs and livestock, large population of susceptible humans, large number of slaughterhouses, arable land and moisture, were considered the most important risk factors.

The strength of our study is that for the first time we conducted such study in Iran and it was a national study in its kind. The limitation might be considered as missing data during the data collection.

Conclusion

We could show that hydatidosis is prevalent in different parts of Iran and the rate of infection is variable due to different variables mentioned in the text. The use of maps can provide reliable estimates of the population at risk. GIS is an effective and inexpensive tool for investigating the distribution of effective factors on health that can be used with high ease and speed at different levels of health systems.

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Conflict of interest

The authors declare that there is no conflict of interest.

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