Journal of Helminthology

cambridge.org/jhl

Research Paper

Cite this article: Jamshidi A, Haniloo A, Fazaeli A, Ghatee MA (2020). Effects of geographical and climatic factors on cystic echinococcosis in south-western Iran. *Journal of Helminthology* **94**, e175, 1–8. https://doi.org/10.1017/S0022149X20000553

Received: 10 May 2020
Accepted: 19 June 2020

Key words:
Cystic echinococcosis; livestock; geographical information system; geo-climatic; Iran

Author for correspondence:
M.A. Ghatee,
E-mail: ghateea1980@gmail.com and
A. Haniloo,
Email: hani@zums.ac.ir

CAMBRIDGE UNIVERSITY PRESS

Effects of geographical and climatic factors on cystic echinococcosis in south-western Iran

A. Jamshidi[1], A. Haniloo[1], A. Fazaeli[1] and M.A. Ghatee[2,3]

[1]Department of Medical Parasitology and Mycology, School of Medicine, Zanjan University of Medical Sciences, Zanjan, Iran; [2]Cellular and Molecular Research Center, Yasuj University of Medical Sciences, Yasuj, Iran and [3]Department of Parasitology and Mycology, School of Medicine, Yasuj University of Medical Sciences, Yasuj, Iran

Abstract

Cystic echinococcosis (CE) is caused by the larval form of *Echinococcus granulosus* that can cause serious health and economic problems in the endemic foci. CE is globally distributed in various climatic conditions from circumpolar to tropical latitudes. Iran is an important endemic area with a spectrum of weather conditions. The aim of this study was to determine the effects of geo-climatic factors on the distribution of livestock CE in south-western Iran (SWI) in 2016 to 2018. Data of livestock CE were retrieved from veterinary organizations of four provinces of SWI. The geo-climatic factors, including mean annual temperature (MAT), minimum MAT (MinMAT), maximum MAT (MaxMAT), mean annual rainfall (MAR), elevation, mean annual evaporation (MAE), sunny hours, wind speed, mean annual humidity (MAH), slope, frost days and land cover, were analysed using geographical information systems (GIS) approaches. The statistical analysis showed that MAR, frost days, elevation, slope and semi-condensed forest land cover were positively and MAE, MAT, MaxMAT, MinMAT and salt and salinity land cover were negatively correlated with CE occurrence. MAE was shown to be a predictive factor in the stepwise linear logistic regression model. In short, the current GIS-based study found that areas with lower evaporation were the main CE risk zones, though those with lower temperature and higher rainfall, altitude and slope, especially where covered with or in close proximity of semi-condensed forest, should be prioritized for consideration by health professionals and veterinarians for conducting control programmes in SWI.

Introduction

Cystic echinococcosis (CE) is a helminthic zoonosis caused by the canid tapeworms, *Echinococcus granulosus sensu lato*. This disease occurs in a number of herbivorous and omnivorous animals (e.g. sheep, goat, cattle, camel, horse, buffalo, cervid and swine) as intermediate hosts and humans as accidental hosts by ingesting parasite eggs in contaminated water, soil, vegetables, etc. CE is globally distributed and is common in some regions of the Mediterranean Basin, South America, south-western and central Asia, Siberia, western China, northern Africa, southern and eastern Europe and the Middle East (Farhadi *et al*., 2018; Gao *et al*., 2018; Tamarozzi *et al*., 2018; Khademvatan *et al*., 2019; Shafiei *et al*., 2020). In fact, CE has been reported in a wide range of geo-climatic conditions such as circumpolar, temperate, subtropical and tropical zones (Rinaldi *et al*., 2014). Iran, as an endemic area in the Middle East with a variety of ecological and geographical conditions, is a good foci for CE development (Karamian *et al*., 2017). Similar to other parasites, *E. granulosus* biology and transmission are affected by the host–parasite association, behavioural traits, population density, habitat, environment and climatic conditions. For example, *Echinococcus* spp. ova survival can be affected by different geo-temporal parameters, including high temperature, low humidity and aridity (Veit *et al*., 1995; Eckert & Deplazes, 2004; McManus, 2010; Atkinson *et al*., 2013; Yan *et al*., 2016; Byers *et al*., 2019; Kołodziej-Sobocińska, 2019). Understanding how parasites and their transmission are influenced by climatic changes and environmental conditions has become one of the most interesting topics among parasitology researchers (Okolo *et al*., 2012). In recent years, the role of climatic changes and environmental conditions has been evaluated using specific tools and data analysis software programmes. Among the most valuable and functional tools are geographic information systems (GIS) and remote sensing technologies in health system programmes (Yilma & Malone, 1998; Ghatee *et al*., 2013; Lyseen *et al*., 2014). GIS technology, as a computer-based system, analyses geospatial-referenced data and plays an important role in the surveillance of parasitic diseases. Researchers have used these approaches to study the interactions of parasites, hosts and reservoirs with geo-climatic factors, identify high- or low-risk areas for the disease spread and plan control strategies (Danson *et al*., 2004; Rinaldi *et al*., 2006; Brundu *et al*., 2014). Although CE is a health problem in the southern and northern hemispheres (Eckert & Deplazes, 2004), most GIS-based studies have investigated the correlation between eco-geographical factors

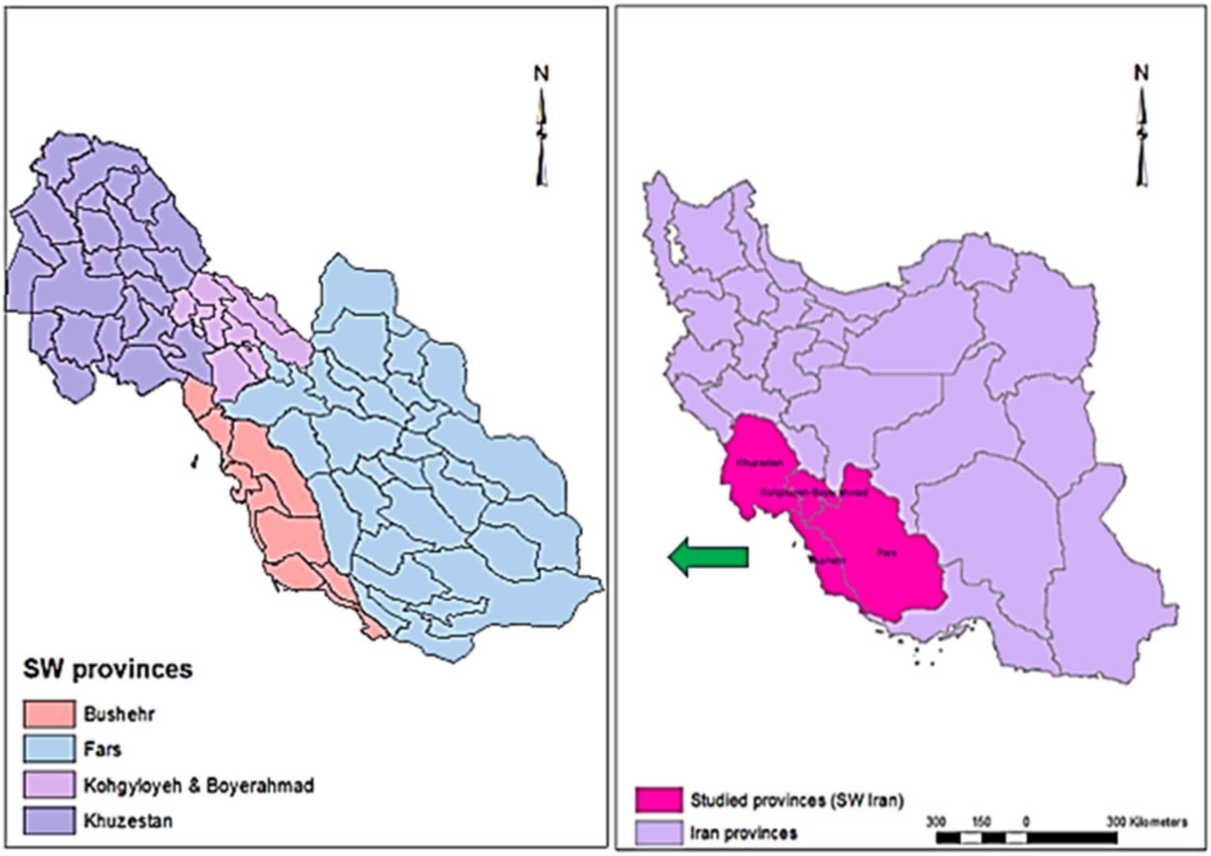

Fig. 1. Location of studied areas in south-western Iran.

and the distribution of alveolar echinococcosis, and only a few studies have addressed the spatial distribution of CE using this approach (Staubach *et al.*, 2001; Danson *et al.*, 2004; Pleydell *et al.*, 2004; Graham *et al.*, 2005; Cringoli *et al.*, 2007). Therefore, in this study, we sought to determine the effects of geo-climatic factors on CE in south-western Iran (SWI) using the GIS approach during 2016–2018.

Materials and methods

Study area

SWI (fig. 1), with a surface area of about 230,567 km^2, is located at approximately 27°N–31°N latitude and 47°E–55°E longitude and inhabits a population of 11.5 million people. The studied area consists of 74 counties in the four provinces of Khuzestan (27 counties), Fars (29 counties), Bushehr (ten counties), and Kohgiluyeh and Boyerahmad (eight counties). There are various climatic regions in SWI, including the Zagros mountain range extending from north to south, with moderately cold winters and temperate summers, plains with rainy mild winters and hot and dry summers and coastal regions of the Persian Gulf, with mild winters and hot and humid summers. These geo-climatic variations cause a variety of plants and land cover, and, consequently, various domestic and wild animals in SWI. The main native domestic animals in this area include sheep, goat, cattle, camel, buffalo, horse, donkey, dog and cat, and wild animals are deer, wild goat, ram, ewe, fox, wolf, jackal, bear and panther (Ghasem *et al.*, 2012; Sagheb-Talebi *et al.*, 2014). According to the Veterinary Bureau consensus, the population of small and large livestock was over 13 million in these provinces during 2016–2018. In detail, it was about 6.2, 4.4, 2.2 and 1 million in Khuzestan, Fars, Kohgiluyeh and Boyerahmad, and Bushehr provinces, respectively. These areas are dominated by different land covers, ranging from forests and irrigated and rich agricultural lands to bare and salty areas. Altitude varies from Dena Mountain (4283 m, as the second highest summit of Iran) in the Zagros Mountains to the lowest grounds in Khuzestan and Bushehr provinces, where there are tens of hundreds of kilometres of coastal areas alongside the Persian Gulf. Various urban, rural and nomadic populations live in SWI. Nomadic tribes live on herding and migrate annually from warm areas to cold ones – that is, from highland pastures in summer (Yailaq) to winter habitations (Qishlag) and vice versa, with their livestock and shepherd dogs. These animals have been found to play a role in the prevalence of some parasitological diseases in SWI (Sarkari *et al.*, 2010; Ghatee *et al.*, 2018; Kanannejad *et al.*, 2019; Moshfe *et al.*, 2019; Ghadimi-Moghadam *et al.*, 2020).

Livestock CE data collection

Comprehensive information about slaughtered livestock (e.g. number and type of animals, infection type, infected tissue, carcass weight, etc.) is routinely recorded by the Iranian National Veterinary Organization. Therefore, we retrieved the required data, including the total number and types of livestock (i.e. goat, sheep, cattle, camel and buffalo) infected with CE, from the veterinary bureaus of provinces of SWI for a three-year period (2016–2018). The data were categorized based on the livestock species

https://doi.org/10.1017/S0022149X20000553 Published online by Cambridge University Press

Table 1. Province-based distribution of livestock CE in south-western Iran (2016–2018).

South-western Iran (overall)	Total	Sheep	Goat	Cattle	Camel	Buffalo
Livestock population, *N* (%)	13,908,122	6,229,483 (44.8)	6,594,878 (47.4)	976,242 (7.0)	19,237 (0.1)	88,282 (0.6)
Slaughtered livestock, *N* (%)	3,984,165	1,904,736 (47.8)	1,785,481 (44.8)	259,754 (6.5)	6634 (0.2)	27,560 (0.7)
Infected livestock, *N* (%)	358,003 (9.0)	190,072 (10.0)	137,271 (7.7)	26,932 (10.4)	518 (7.8)	3210 (11.6)
Fars province						
Livestock population, *N* (%)	4,356,312	1,753,849 (40.3)	2,342,671 (53.8)	243,157 (5.6)	16,048 (0.4)	587 (0.01)
Slaughtered livestock, *N* (%)	1,452,892	501,544 (34.5)	864,127 (59.5)	80,967 (5.6)	5966 (0.4)	288 (0.02)
Infected livestock, *N* (%)	110,475 (7.6)	45,167 (9.0)	58,247 (6.7)	6591 (8.1)	459 (7.7)	11 (3.8)
Khuzestan province						
Livestock population, *N* (%)	6,194,712	3,420,587 (55.2)	2,192,963 (35.4)	491,799 (7.9)	1767 (0.03)	87,596 (1.4)
Slaughtered livestock, *N* (%)	1,962,997	1,143,526 (58.3)	630,987 (32.1)	160,633 (8.2)	589 (0.03)	27262 (1.4)
Infected livestock, *N* (%)	174,533 (8.9)	109,105 (9.5)	43,825 (7.0)	18,357 (11.4)	48 (8.1)	3198 (11.7)
Bushehr province						
Livestock population, *N* (%)	1,233,288	241,734 (19.6)	796,617 (64.6)	193,416 (15.7)	1422 (0.1)	99 (0.01)
Slaughtered livestock, *N* (%)	137,032	37,014 (27)	88,513 (64.6)	11,416 (8.3)	79 (0.06)	10 (0.008)
Infected livestock, *N* (%)	11,396 (8.3)	3028 (8.2)	7651 (8.7)	705 (6.2)	11 (14)	1 (10.0)
Kohgiluyeh and Boyerahmad province						
Livestock population, *N* (%)	2,123,610	813,313 (38.3)	1,262,627 (60)	47,870 (2.3)	–	–
Slaughtered livestock, *N* (%)	431,244	222,652 (51.7)	201,854 (46.8)	6738 (1.6)	–	–
Infected livestock, *N* (%)	61,599 (14.3)	32,772 (14.7)	27,548 (13.7)	1279 (19.0)	–	–

– There is no camel and buffalo husbandry.

belonging to each county and then entered into Microsoft Excel, (2016).

Geographical and climatic data collection

Meteorological data included mean annual rainfall (MAR), mean annual humidity (MAH), mean annual evaporation (MAE), the annual frequency of frost days, the mean number of sunny hours, mean annual wind speed, mean annual temperature (MAT), minimum MAT (MinMAT) and maximum MAT (MaxMAT). The data for the study period were retrieved from all the 62 synoptic stations (stations that collect meteorological data every 3 or 6 h) located in the studied areas. MAR, MAH and MAE raster layers were developed by the kriging interpolation method, and other meteorological layers were generated by the tension-based spline interpolation method with a resolution grid of 2×2 km after examining various interpolation models. Digital elevation model (DEM) raster layers and land cover vector layers (including features covering the province's surface) were retrieved from the Provincial Department of Agricultural Affairs. Layers belonging to the four provinces were merged to obtain one layer including all the SWI areas for each mentioned map. The slope raster layer was generated based on the DEM map by calculating the maximum rate of change in value between each cell and its neighbours by using the spatial analyst tool.

Geographical and climatic analysis

All the geo-climatic data were analysed using ArcGIS version 10.5 (http://www.esri.com/arcgis). The shapefile polygon layer of the SWI counties whose rate of total infection was previously enrolled within its attribute was used as the basic layer. The geometric intersection of the counties layer and the land cover polygonal shapefile was computed by an identity tool and then dissolved to unify all land cover feature polygons for each county. The sum of area (square km) of each land cover feature was calculated using the geometry tool for each county. Mean pixel values of DEM, slope, MAR, MAT, MaxMAT, MinMAT, MAH, MAE, frost days and sunny hours' raster layers were calculated for each county by zonal statistics in the related tables. A final table encompassing all of the aforementioned data for SWI counties was drawn, and then it was converted to Excel format for statistical analysis.

Statistical analysis

Having described the geographical distribution of livestock CE in SWI, in the first step of statistical analysis, we investigated the correlation between the total infected livestock rate (dependent variable) and geo-climatic factors (independent variables). Then, since all the variables in the study were quantitative, a stepwise linear regression model was developed for variables that had a significant correlation with the dependent factor to investigate the probable predictors. The analyses were carried out using SPSS, version 21 (IBM Corp).

Results

Geographical distribution of livestock CE in SWI

The overall prevalence of CE in slaughtered livestock was 9% in SWI. The highest and lowest rates of infection belonged to buffalo (11.6%) and goat (7.7%). Also, the overall highest infection

https://doi.org/10.1017/S0022149X20000553 Published online by Cambridge University Press

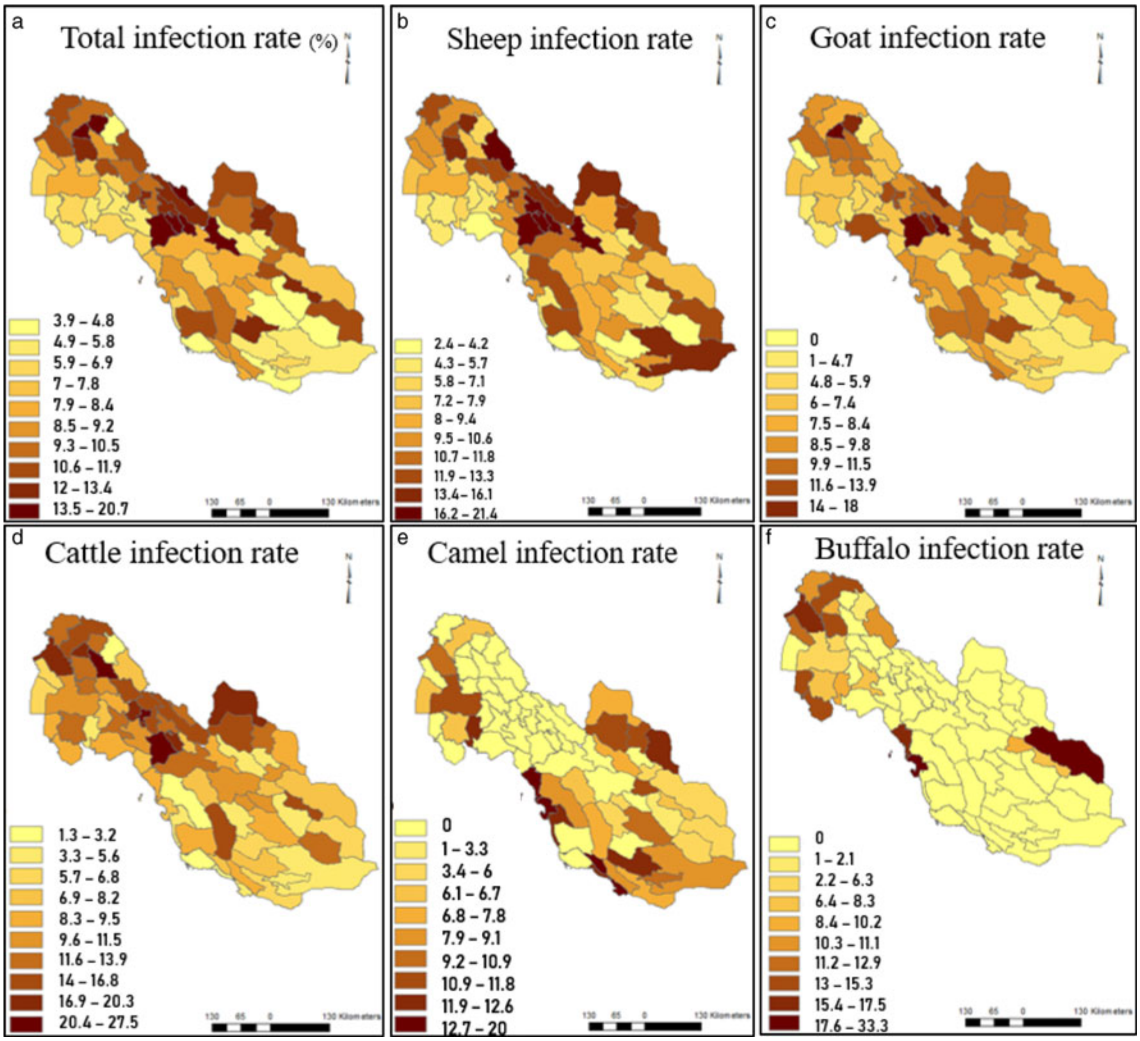

Fig. 2. Prevalence (infection rate %) and geographical distribution of livestock CE in south-western Iran. (a) Distribution of total infected livestock. (b) Infected sheep were mostly found in eastern, south-eastern and northern counties of Fars, some north-western, northern and eastern counties in Khuzestan, and approximately throughout Kohgiluyeh and Boyerahmad province. (c) The highest prevalence of infected goats was in north of Khuzestan, centre of Kohgiluyeh and Boyerahmad, and some parts in north, west and south-west of Fars, and south-east of Bushehr province. (d) North-western, central, northern and western counties of Khuzestan, eastern counties of Kohgiluyeh and Boyerahmad, and northern areas of Fars province were shown to be the main infected areas for cattle. (e) Infected camels were mostly found in the west of Khuzestan, north and south of Fars, and west and centre of Bushehr province. (f) Infected buffalo were mostly observed in north-west, centre and west of Khuzestan, two eastern counties of Fars and western counties of Bushehr province.

rate was related to Kohgiluyeh and Boyerahmad (14.3%) and the lowest infection rate was found in Fars province (7.6%) (table 1). Based on the geographical distribution of CE, the most infected counties were distributed throughout a hypothetical band stretching from north-west (north and centre of Khuzestan province) towards central and south-eastern areas (i.e. from Kohgiluyeh and Boyerahmad to the centre of Fars province). The distribution of infected livestock is shown in fig. 2(a–f).

Effects of geographical and climatic factors on CE

Pearson correlation analysis showed that MAR, frost days, elevation, slope and surface of semi-condensed forest landcover were positively associated with CE rate in SWI, and rainfall was found to have the highest correlation. MAE, MAT, MaxMAT, MinMAT and salinity land cover showed a significant negative correlation ($P < 0.05$) with the CE occurrence (table 2 and fig. 3). A decreasing trend in CE rate was found with the increase in sunny hours in most parts of SWI (areas with 3358–3652 sunny hours based on the map); however, no significant correlation was found in this regard ($P = 0.09$; fig. 3). Also, there was no significant correlation between humidity, wind speed and land covers of bare lands, thin rangelands, condensed rangelands, irrigated farms and gardens, semi-condensed rangelands, riverbeds, swamps, urban, sandy areas and canebrakes with CE infection rate, although an inverse R was recorded for them. Positive but not significant correlations were shown between the distribution of CE and condensed forest rained farms and gardens, and thin forest land covers (table 2). To evaluate the effect of these factors on the occurrence of CE, a stepwise linear regression model was developed with the model fitness of approximately 60% (R square = 0.601). MAE ($P < 0.001$; beta = −0.60) was found to be a predictive factor in the stepwise model, while MAT ($P = 0.841$; beta = −0.024), MaxMAT ($P = 0.85$; beta = −0.02), MinMAT ($P = 0.94$; beta = −0.01), MAR ($P = 0.67$; beta = 0.07),

https://doi.org/10.1017/S0022149X20000553 Published online by Cambridge University Press

Table 2. Pearson correlation between geo-climatic factors and total rate of CE in south-western Iran.

Geo-climatic factors	Pearson correlation	
	R	*P*-value
Evaporation	−0.600	0.000*
Sunny hours	−0.201	0.092
Frost days	0.284	0.017*
Humidity	−0.128	0.286
MAR	0.517	0.000*
MaxMAT	−0.383	0.001*
MinMAT	−0.359	0.002*
MAT	−0.349	0.003*
Elevation	0.312	0.008*
Wind speed	−0.147	0.220
Slope	0.426	0.000*
Landcovers		
Bare land	−0.090	0.455
Canebrake	−0.114	0.344
Condensed forest	0.109	0.366
Condensed rangeland	−0.113	0.349
Dry (rained farm and garden)	0.382	0.144
Irrigated farm and garden	−0.171	0.153
Riverbed	−0.130	0.280
Salt land and salinity	−0.278	0.019*
Sandy area	−0.156	0.194
Semi-condensed forest	0.240	0.043*
Semi-condensed rangeland	−0.004	0.971
Swamp	−0.134	0.266
Thin forest	0.021	0.864
Thin rangeland	−0.184	0.125
Urban	−0.156	0.195
Water area	−0.103	0.395

*Significant factors (*P*-value < 0.05).
– Negative correlation with CE occurrence.
MAR, mean annual rainfall; MaxMAT, maximum mean annual temperature; MinMAT, minimum mean annual temperature; MAT, mean annual temperature.

elevation ($P = 0.89$; beta = −0.01), slope ($P = 0.65$; beta = −0.05), frost days ($P = 0.84$; beta = 0.02), semi-condensed forests ($P = 0.72$; beta = −0.04) and salinity land covers ($P = 0.54$; beta = −0.06) were excluded from the model.

Discussion

The current study revealed that MAE is the most important predictor of livestock CE in SWI, although CE infection rate was also positively correlated with MAR, frost days, elevation, slope and surface of semi-condensed forest land cover, and negatively with MAT, MaxMAT, MinMAT and salinity land cover. There was a trend between sunny hours and CE occurrence in this region.

The effect of MAE as the most important predictor of CE distribution in SWI is probably due to its impact on soil aridity that decreases egg viability and transmission capability. Some studies confirmed that *Echinococcus* spp. egg is sensitive to dryness and survives only for a short time if exposed to direct sunlight and dryness (Thevenet *et al*., 2005). The study by Staubach *et al*. (2001) showed dryness as a limiting factor in the tenacity of *Echinococcus multilocularis* oncospheres in eggs. Furthermore, increased evaporation is related to the expansion of drought and salt lands, and reduced growth of plants and rangelands, which can provide a hostile environment for egg survival (Tajbakhsh *et al*., 2015).

Our study revealed an inverse relationship between salinity and CE occurrence in SWI, explaining why husbandry in this area is less common than elsewhere. On the other hand, due to the presence of salt in this area and its ovicidal effect, the parasite's life cycle will most likely not be completed (Craig & Macpherson, 1988)

Semi-condensed forests directly affect CE occurrence in SWI. In recent years, climatic changes and drought have increased in the Middle East, especially in Iran (as a country with more than 82% of its area locates in arid and semi-arid zones), where the average rainfall (250 mm) has decreased to one-third of the world's rainfall average (860 mm) (Amiri & Eslamian, 2010; Sobhani *et al*., 2020). Drought is more severe in some parts of Iran such as south-western, southern, south-eastern and central regions (Raziei *et al*., 2009; Abarghouei *et al*., 2011). Climate change and drought have forced rural and nomadic communities to migrate and settle in greener places such as semi-condensed forest areas, river banks and green rangeland areas, and wherever water sources and feedstuff are available for their livestock (Keshavarz *et al*., 2013; Rashednasab *et al*., 2018). Higher soil wetness and more shadow in these regions may increase the chance of survival of eggs excreted by the definitive host, leading to the infection of intermediate hosts. Also, semi-condensed forests, as the habitat of carnivorous canids such as stray dogs, wolves, foxes and jackals, as the definitive hosts for *E. granulosus*, are mostly located at higher-altitude hillsides and in the close proximity of mountainous villages and nomadic shelters, which are suitable conditions for the maintenance of the parasite cycle (Otero-Abad & Torgerson, 2013; Farimani *et al*., 2017).

Other significant factors related to CE in the present study were rainfall, temperature, elevation, slope and frost days. According to fig. 3, there is a comprehensive overlap between these factors. For example, with increasing levels of elevation, elevated MAR and disease burden have been reported. The effect of MAR on CE distribution is understandable. Rainfall contributes to the expansion of green rangelands and forests, and increases the amount of forage for livestock, which results in higher herding and infection rates. In addition, rainfall can increase the relative humidity and the balance between temperature and humidity, which is needed for the survival of parasite eggs. There was a negative association between different temperature models and CE in our study, and the schematic temperature map (fig. 3) showed that higher rates of CE infection have been found in areas with 15°C–29°C MAT, while CE prevalence was reduced in areas where MAT was above 30°C. This is because of higher susceptibility of parasite eggs to higher temperatures, dryness and dehydration. For example, in some studies it was observed that *Echinococcus* eggs were disinfected by high temperatures (hot water of 85°C or above) and desiccation, while they could survive in freezing conditions. However, they can be killed by freezing at −80°C for 48 h or −70°C for four days (Colli &

https://doi.org/10.1017/S0022149X20000553 Published online by Cambridge University Press

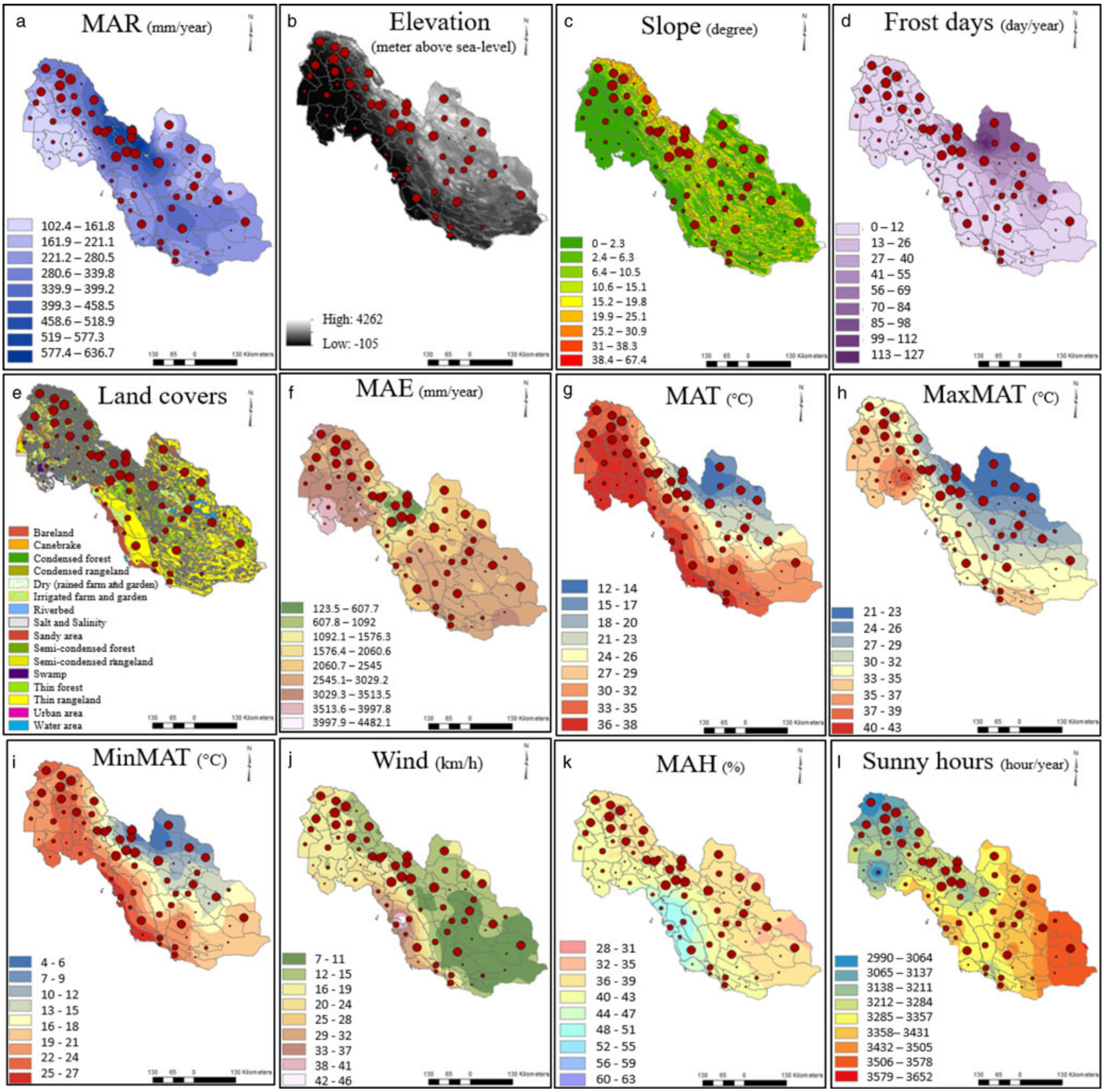

Fig. 3. Geo-climatic factors and CE distribution in south-western Iran. MAR (a), elevation (b), slope (c), frost days (d) and semi-condensed forest land cover (e) were positively correlated with CE rate. MAE (f), MAT (g), MaxMAT (h), MinMAT (i) and salt land (e) were negatively associated with CE incidence. No significant relationship was found between wind velocity (j) and MAH (k) and CE rate, while a non-significant association was found between sunny hours (l) and disease prevalence. Maps show that most counties with the highest CE rate had 458–636 mm annual rainfall, 41–98 frost days, 10–30 degree slope, 123–1576 mm/day evaporation and 15–29°C MAT.

Williams, 1972; Eckert & Deplazes, 2004; Federer *et al.*, 2015; Cédric *et al.*, 2019). The results of the Harriott *et al.* (2019) study in Queensland, Australia, showed that CE infection rate significantly increased with higher rainfall, relative humidity and temperature. Veit *et al.* (1995) presented that *E. multilocularis* eggs were highly sensitive to elevated temperatures and to desiccation as far as the eggs' infectivity was lost after 3 h at 45°C. Kern *et al.* (2004) presented that *E. multilocularis* eggs can remain infective for months under suitable conditions such as low temperatures and high humidity.

Although in the present study there was no significant correlation between MAH and CE prevalence, most counties with higher rates of infection were within 35–40% relative humidity range. In some counties of Bushehr and Khuzestan provinces with high humidity (>40%), the prevalence of CE was lower than other counties in SWI. This finding can be explained by the higher MAT, MaxMAT and MAE in these areas, which can reduce the infection rate.

It should be noted that due to the lack of accurate information as to the geographical distribution of the parasite's definitive and

https://doi.org/10.1017/S0022149X20000553 Published online by Cambridge University Press

accidental hosts (carnivores and human) in SWI during the present study, further comprehensive studies are recommended to determine the effects of geo-climatic factors on the prevalence of CE in the parasite's definitive and intermediate hosts in SWI and other regions of Iran.

Conclusion

In short, GIS-based analysis showed that some of the geo-climatic factors such as MAE, as the main predictive factor, and MAT, MinMAT, MaxMAT, MAR, elevation, slope, land cover of the semi-condensed forest and salinity lands had significant correlation with CE distribution in SWI. Accordingly, areas with lower evaporation and temperature and higher rainfall, especially those covered by semi-condensed forest, mostly found in mountainous higher altitudes, should be prioritized for consideration as probable CE risk zones. GIS, as a powerful descriptive and analytical tool that identifies risk factors associated with livestock population and the distribution of hydatidosis, can help health professionals and veterinarians identify high-risk regions and assess the performance of control programmes in SWI.

Acknowledgements. This article is part of a PhD thesis in medical parasitology (number A-12-95-13) supported by Zanjan University of Medical Sciences. Special thanks and appreciation to the Veterinary Bureau consensus and Weather Bureau in Fars, Khuzestan, Kohgiluyeh and Boyerahmad, and Bushehr provinces for their assistance in collecting meteorological, geo-climatic data and information of livestock's CE in SWI required for this study. We also thank all collaborators involved in the project.

Financial support. This article was financially supported by Zanjan University of Medical Sciences (No: A-12-95-13) and approved by Ethics committee of Zanjan Univwersity of Medical Sciences (Code: IR.ZUMS.REC.1397.252).

Conflicts of interest. None.

References

Abarghouei HB, Zarch MAA, Dastorani MT, Kousari MR and Zarch MS (2011) The survey of climatic drought trend in Iran. *Stochastic Environmental Research and Risk Assessment* **25**, 851.

Amiri M and Eslamian S (2010) Investigation of climate change in Iran. *Journal of Environmental Science and Technology* **3**, 208–216.

Atkinson JAM, Gray DJ, Clements AC, Barnes TS, McManus DP and Yang YR (2013) Environmental changes impacting Echinococcus transmission: research to support predictive surveillance and control. *Global Change Biology* **19**, 677–688.

Brundu D, Piseddu T, Stegel G, Masu G, Ledda S and Masala G (2014) Retrospective study of human cystic echinococcosis in Italy based on the analysis of hospital discharge records between 2001 and 2012. *Acta Tropica* **140**, 91–96.

Byers JE, Schmidt J, Pappalardo P, Haas SE and Stephens PR (2019) What factors explain the geographical range of mammalian parasites? *Proceedings of the Royal Society B* **286**, 20190673.

Cédric G, Frits F, Silivia M, *et al.* (2019) Inactivation of parasite transmission stages: efficacy of treatments on foods of non-animal origin. *Trends in Food Science & Technology* **91**, 12–23.

Colli CW and Williams J (1972) Influence of temperature on the infectivity of eggs of *Echinococcus granulosus* in laboratory rodents. *The Journal of Parasitology* **58**, 422–426.

Craig P and Macpherson C (1988) Sodium hypochlorite as an ovicide for echinococcus. *Annals of Tropical Medicine & Parasitology* **82**, 211–213.

Cringoli G, Rinaldi L, Musella V, Veneziano V, Maurelli MP, Di Pietro F, Frisiello M and Di Pietro S (2007) Geo-referencing livestock farms as tool for studying cystic echinococcosis epidemiology in cattle and water buffaloes from southern Italy. *Geospatial Health* **2**, 105–111.

Danson F, Bowyer P, Pleydell D and Craig P (2004) *Echinococcus multilocularis*: the role of satellite remote sensing. GIS and spatial modelling. *South-East Asian Journal of Tropical Medicine and Public Health* **35**, 189–193.

Eckert J and Deplazes P (2004) Biological, epidemiological, and clinical aspects of echinococcosis, a zoonosis of increasing concern. *Clinical Microbiology Reviews* **17**, 107–135.

Farhadi M, Haniloo A, Rostamizadeh K and Faghihzadeh S (2018) Efficiency of flubendazole-loaded mPEG-PCL nanoparticles: a promising formulation against the protoscoleces and cysts of *Echinococcus granulosus*. *Acta Tropica* **187**, 190–200.

Farimani SM, Raufirad V, Hunter R and Lebailly P (2017) Coping strategies during drought: the case of rangeland users in southwest Iran. *Rangelands* **39**, 133–142.

Federer K, Armua-Fernandez MT, Hoby S, Wenker C and Deplazes P (2015) In vivo viability of *Echinococcus multilocularis* eggs in a rodent model after different thermo-treatments. *Experimental Parasitology* **154**, 14–19.

Gao CH, Wang JY, Shi F, Steverding D, Wang X, Yang YT and Zhou XN (2018) Field evaluation of an immunochromatographic test for diagnosis of cystic and alveolar echinococcosis. *Parasit Vectors* **11**, 311.

Ghadimi-Moghadam A, Salahi M, Ghatee MA, Ghadimi-Moghadam A, Kanannejad Z, Mosavi A, Ramshk O and Khoramrooz S (2020) Environmental and climatic factors influencing the occurrence and distribution of tuberculosis in southwest Iran: a GIS-based study. *Acta Medica Mediterranea* **36**, 557–563.

Ghasem A, Shamsipour A, Miri M and Safarrad T (2012) Synoptic and remote sensing analysis of dust events in southwestern Iran. *Natural Hazards* **64**, 1625–1638.

Ghatee MA, Sharifi I, Haghdoost AA, Kanannejad Z, Taabody Z, Hatam G and Abdollahipanah A (2013) Spatial correlations of population and ecological factors with distribution of visceral leishmaniasis cases in southwestern Iran. *Journal of Vector Borne Diseases* **50**, 179.

Ghatee MA, Haghdoost AA, Kooreshnia F, Kanannejad Z, Parisaie Z, Karamian M and Moshfe A (2018) Role of environmental, climatic risk factors and livestock animals on the occurrence of cutaneous leishmaniasis in newly emerging focus in Iran. *Journal of Infection and Public Health* **11**, 425–433.

Graham A, Danson F and Craig P (2005) Ecological epidemiology: the role of landscape structure in the transmission risk of the fox tapeworm *Echinococcus multilocularis* (Leukart 1863) (Cestoda: Cyclophyllidea: Taeniidae). *Progress in Physical Geography* **29**, 77–91.

Harriott L, Gentle M, Traub R, Cobbold R and Magalhães RS (2019) Geographical distribution and risk factors for *Echinococcus granulosus* infection in peri-urban wild dog populations. *International Journal for Parasitology: Parasites and Wildlife* **10**, 149–155.

Kanannejad Z, Haghdoost A, Ghatee MA, Azarifar F, Shahriari S and Moshfe A (2019) Effect of human, livestock population, climatic and environmental factors on the distribution of brucellosis in southwest Iran. *Acta Medica Mediterranea* **36**, 557

Karamian M, Haghighi F, Hemmati M, Taylor WR, Salehabadi A and Ghatee MA (2017) Heterogenity of *Echinococcus canadensis* genotype 6 - the main causative agent of cystic echinococcosis in Birjand, Eastern Iran. *Vet Parasitol* **245**, 78–85.

Kern P, Ammon A, Kron M, Sinn G, Sander S, Petersen LR, Gaus W and Kern P (2004) Risk factors for alveolar echinococcosis in humans. *Emerging Infectious Diseases* **10**, 2088.

Keshavarz M, Karami E and Vanclay F (2013) The social experience of drought in rural Iran. *Land Use Policy* **30**, 120–129.

Khademvatan S, Majidiani H, Foroutan M, Tappeh KH, Aryamand S and Khalkhali H (2019) *Echinococcus granulosus* genotypes in Iran: a systematic review. *Journal of Helminthology* **93**, 131–138.

Kołodziej-Sobocińska M (2019) Factors affecting the spread of parasites in populations of wild European terrestrial mammals. *Mammal Research* **64**, 301–318.

Lyseen AK, Nøhr C, Sørensen EM, Gudes O, Geraghty E, Shaw N, Bivona-Tellez C and Group IHGW (2014) A review and framework for categorizing current research and development in health related geographical information systems (GIS) studies. *Yearbook of Medical Informatics* **23**, 110–124.

McManus DP (2010) Echinococcosis with particular reference to Southeast Asia. *Advances in Parasitology* **72**, 267–303.

Moshfe A, Sarkari B, Arefkhah N, Nikbakht R, Shahriarirad R, Rezaei Z, Jamshidi A and Moradian F (2019) Seroepidemiological study of cystic echinococcosis in nomadic communities in the southwest of Iran: A population-based study. *Journal of Immunoassay and Immunochemistry* **40**, 183–192.

Okolo M, Nnadi N, Onyedibe K and Ita OI (2012) Will climate change affect parasite-host relationship? *Jos Journal of Medicine* **6**, 27–31.

Otero-Abad B and Torgerson PR (2013) A systematic review of the epidemiology of echinococcosis in domestic and wild animals. *PLoS Neglected Tropical Diseases* **7**, e2249.

Pleydell D, Raoul F, Tourneux F, Danson F, Graham A, Craig P and Giraudoux P (2004) Modelling the spatial distribution of *Echinococcus multilocularis* infection in foxes. *Acta Tropica* **91**, 253–265.

Rashednasab K, Ahmadvand M and Sharifzadeh M (2018) Drought Analysis: behavior management and its influencing factors in nomad of Darila region, Gachsaran County. *Journal of Rural Research* **9**, 88–101.

Raziei T, Saghafian B, Paulo AA, Pereira LS and Bordi I (2009) Spatial patterns and temporal variability of drought in western Iran. *Water Resources Management* **23**, 439.

Rinaldi L, Musella V, Biggeri A and Cringoli G (2006) New insights into the application of geographical information systems and remote sensing in veterinary parasitology. *Geospatial Health* **1**, 33–47.

Rinaldi F, Brunetti E, Neumayr A, Maestri M, Goblirsch S and Tamarozzi F (2014) Cystic echinococcosis of the liver: a primer for hepatologists. *World Journal of Hepatology* **6**, 293.

Sagheb-Talebi K, Pourhashemi M and Sajedi T (2014) *Forests of Iran: a treasure from the past, a hope for the future*, vol. **10**. Switzerland, Springer, pp. 8–151.

Sarkari B, Sadjjadi S, Beheshtian M, Aghaee M and Sedaghat F (2010) Human cystic Echinococcosis in Yasuj district in Southwest of Iran: an epidemiological study of seroprevalence and surgical cases over a ten-year period. *Zoonoses and Public Health* **57**, 146–150.

Shafiei R, Ghatee M, Jafarzadeh F, Javanshir Z and Karamian M (2020) Genotyping and phylogenetic analysis of unusually located hydatid cysts isolated from humans in north-east Iran. *Journal of Helminthology* **94**, 1–5.

Sobhani B, Zengir VS and Yazdani MH (2020) Modelling, evaluation and simulation of drought in Iran, southwest Asia. *Journal of Earth System Science* **129**, 1–13.

Staubach C, Thulke H-h, Tackmann K, Hugh-Jones M and Conraths FJ (2001) Geographic information system-aided analysis of factors associated with the spatial distribution of *Echinococcus multilocularis* infections of foxes. *The American Journal of Tropical Medicine and Hygiene* **65**, 943–948.

Tajbakhsh S, Eisakhani N and Fazl KA (2015) Assessment of meteorological drought in Iran using standardized precipitation and evapotranspiration index (SPEI). *Journal of the Earth and Space Phisics* **41**, 313–321 (in Persian).

Tamarozzi F, Akhan O, Cretu CM, *et al.* (2018) Prevalence of abdominal cystic echinococcosis in rural Bulgaria, Romania, and Turkey: a cross-sectional, ultrasound-based, population study from the HERACLES project. *Lancet Infect Dis* **18**, 769–778.

Thevenet PS, Jensen O, Drut R, Cerrone GE, Grenóvero MS, Alvarez HM, Targovnik HM and Basualdo JA (2005) Viability and infectiousness of eggs of *Echinococcus granulosus* aged under natural conditions of inferior arid climate. *Veterinary Parasitology* **133**, 71–77.

Veit P, Bilger B, Schad V, Schäfer J, Frank W and Lucius R (1995) Influence of environmental factors on the infectivity of *Echinococcus multilocularis* eggs. *Parasitology* **110**, 79–86.

Yan C, Liang L-J, Zheng K-Y and Zhu X-Q (2016) Impact of environmental factors on the emergence, transmission and distribution of Toxoplasma gondii. *Parasites & vectors* **9**, 137.

Yilma J and Malone J (1998) A geographic information system forecast model for strategic control of fasciolosis in Ethiopia. *Veterinary Parasitology* **78**, 103–127.