Journal of Infection and Public Health (2015) **8**, 481—486

http://www.elsevier.com/locate/jiph

Developing a climate-based risk map of fascioliasis outbreaks in Iran

Mansour Halimi[a,*], **Manuchehr Farajzadeh**[b], **Mahdi Delavari**[c], **Mohsen Arbabi**[c]

[a] *Department of Climatology, Tarbiat Modares University, Tehran, Iran*
[b] *Department of Remote Sensing and GIS, Tarbiat Modares University, Tehran, Iran*
[c] *Department of Medical Parasitology, Faculty of Medicine, Kashan University of Medical Science, Kashan, Iran*

Received 15 December 2014; received in revised form 3 March 2015; accepted 3 April 2015

KEYWORDS
Ollerenshaw fascioliasis risk index;
Climate;
Gilan province;
Iran

Summary The strong relationship between climate and fascioliasis outbreaks enables the development of climate-based models to estimate the potential risk of fascioliasis outbreaks. This work aims to develop a climate-based risk map of fascioliasis outbreaks in Iran using Ollerenshaw's fascioliasis risk index incorporating geographical information system (GIS). Using this index, a risk map of fascioliasis outbreaks for the entire country was developed. We determined that the country can be divided into 4 fascioliasis outbreak risk categories. Class 1, in which the Mt value is less than 100, includes more than 0.91 of the country's area. The climate in this class is not conducive to fascioliasis outbreaks in any month. Dryness and low temperature in the wet season (December to April) are the key barriers against fascioliasis outbreaks in this class. The risk map developed based on climatic factors indicated that only 0.03 of the country's area, including Gilan province in the northern region of Iran, is highly suitable to fascioliasis outbreaks during September to January. The Mt value is greater than 500 in this class. Heavy rainfall in the summer and fall, especially in Rasht, Astara and Bandar Anzaly (≥1000 mm/year), creates more suitable breeding places for snail intermediate hosts.

Introduction

Fascioliasis, an infection caused by the liver flukes fasciola hepatica and *Fasciola gigantica*, has traditionally been considered an important veterinary

---

* Corresponding author. Tel.: +98 9384845389.
E-mail address: M.halimi@modares.ac.ir (M. Halimi).

http://dx.doi.org/10.1016/j.jiph.2015.04.024

disease. It is a major disease in cattle, sheep, goats, buffalo and other ruminants, such as horses and rabbits. The disease has resulted in considerable economic loss due to mortality, liver condemnation, weight loss, anemia, lethargy and reduced quality and quantity of milk production [1]. In contrast, human fascioliasis has always been viewed as a secondary disease [2,3]. Geographical distributions of the free living stages and the intermediate molluscan host, *Lymnaea truncatula*, are dependent on a range of climatic factors. Liver flukes require certain climatic and environmental conditions for completion of the lifecycle. Specifically, in the presence of suitable livestock hosts, an ambient temperature of above 10 °C and sufficient moisture are required for the development of the free-living and intra-molluscan stages of the parasite and the development and expansion of snail populations [4]. Because *Fasciola hepatica* and *L. truncatula* are vulnerable to desiccation, high levels of moisture, such as fresh bodies of water and relative air humidity, are also required. The deep relationship between climate and fascioliasis enables the development of short term forecasting models to estimate the risk of disease occurrence [5]. These short-term forecasts can help to predict fascioliasis incidence and severity at local and regional scales, allowing the development and implementation of improved control strategies [6]. These models are created using various techniques, including process based mechanistic modeling [8] and correlative models based on surveillance data [9] or liver condemnations [10] as well as a current trend toward GIS models [11—13].

Of all the forecast models, the Ollerenshaw index was the first widely used system to predict acute outbreaks and manage control strategies in the UK. It was developed using *F. hepatica* prevalence data and climate data from farms and meteorological stations from 1948 to 1957, with a seasonal index derived from measured rainfall, number of rain days and potential evapotranspiration. The National Animal Disease Information Service (NADIS) currently provides farmers with short-term forecasts of fascioliasis risk based on the Ollerenshaw index [6,7].

Recent estimates suggest that up to 2.4 million or even up to 17 million people are infected with *F. hepatica* in the world. The major associated health problems in cases of fascioliasis are found in Andean countries of South America, northern Africa, Iran, and Western Europe [13].

Although fascioliasis is prevalent in livestock throughout Iran, human infection with fasciola is mainly reported in the littoral region of the Caspian Sea [14]. Nevertheless, sporadic cases of the disease have already been reported from different parts of Iran, including the northern provinces of Gilan and Mazandaran [15]. In Iran, infection of cattle, sheep, buffalo and goats with fasciola hepatica and *F. gigantica* has been reported in many parts of the country. For example, in one study, it was shown that in parts of Gilan, where a human epidemic occurred in 1988, 71.4% of cows were infected with *F. gigantica* and 28.5% with *F. hepatica*. The average rate of infection with fasciola among 445 cows in 3 areas of Gilan was 32.1% [16]. High rates of animal infection have also been reported from the Mazandaran provinces and other parts of Iran, such as the Charmahalobakhtiary, Kermanshah and Kordestan provinces located in western Iran.

Material and methods

Data collection

Climate data for the years 1980—2010 (30 years) were obtained from Iran's Meteorological Organization (IRIMO). Monthly datasets for the following climatic factors were obtained from 34 synoptic stations in Iran: number of days per month with rainfall $\gg$1 mm, total precipitation in mm, maximum, minimum and mean temperature (°C), prevailing wind speed (km/day), and number of hours of sunshine per month.

Ollerenshaw risk model

To calculate *F. hepatica* infection risk, the Ollerenshaw risk model was used. This model, also known as the Mt Index, was proposed by Ollerenshaw and Rowlands [9]. The model is dependent on the interactions between rainfall and temperature, with the monthly fascioliasis risk value (Mt) calculated as below [6]:

$$\mathrm{Mt} = n(R - \mathrm{PE} + 5)$$

n is the number of rainy days, R is the rainfall in inches and PE is the potential evapotranspiration in inches.

This equation was subsequently modified by Ollerenshaw himself (1971—1973) for values of rainfall and evapotranspiration in mm [17]. The modified equation was used in this study shown below:

$$\mathrm{Mt} = \frac{n(R - \mathrm{PE} + 125)}{25}$$

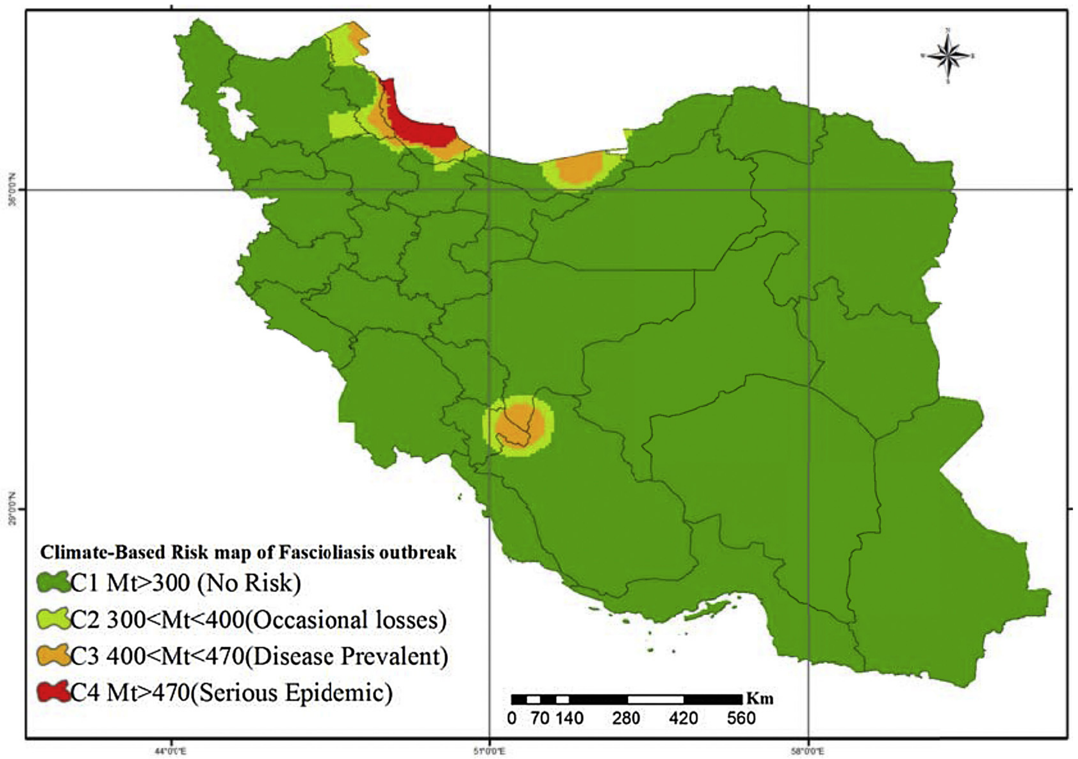

Figure 1 Climate-based risk map of fascioliasis outbreaks in Iran using the Ollerenshaw risk model with the country divided into 4 risk categories.

where Mt is the fascioliasis risk value, n is the number of rain days per month, R is the total rainfall (mm/month), PE is the potential evapotranspiration (mm/month).

In this study, the FAO Penman—Monteith method was used to estimate potential evapotranspiration. This method estimates ET rates for a well-watered reference surface[1] based on physical atmospheric observations of solar radiation, temperature, wind speed, and relative humidity. The climatic factors used in this method include the following: minimum and maximum daily temperature (°C), relative humidity (%), total precipitation (mm), number of hours of sunshine per month and wind speed (km/day).

Potential evapotranspiration (FAO Penman—Monteith):

$$\mathrm{ET}_0 = \frac{0.408(R_\mathrm{n} - G) + \gamma(900/(\overline{T} + 237))\ U_2(e_\mathrm{s} - e_\mathrm{a})}{\Delta + \gamma(1 + 0.34U_2)}$$

ET_0 is the reference evapotranspiration (mm/day), R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T is the air temperature at 2 m height (°C), U_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), $e_\mathrm{s} - e_\mathrm{a}$ is the saturation vapor pressure deficit (kPa).

CROPWAT V8.0 for windows, which was developed by FAO, was used to calculate monthly potential evapotranspiration. Ollerenshaw considered 10 °C the lowest threshold temperature for the development of fascioliasis. An Mt value was first calculated for each month and these monthly values were subsequently added to obtain seasonal Mt values. Mt was set to zero if the average monthly temperature was below 10 °C to reflect the development thresholds for both the free living stages of *F. hepatica* and *L. truncatula*. Months with an Mt value equal to or higher than a critical value

Table 1 Seasonal risk categories for fascioliasis outbreaks according to Ollerenshaw and Rowlands [9].

Class	Index Mt	Risk level
C1	$\mathrm{Mt} \leq 300$	No risk or low risk
C2	$300 \leq \mathrm{Mt} \leq 400$	Occasional loses
C3	$400 \leq \mathrm{Mt} \leq 474$	Disease prevalence
C4	$\mathrm{Mt} > 474$	Serious epidemic

---

[1] The reference surface is a theoretical grass reference crop with a height of 0.12 m, an albedo of 0.23, and a constant surface resistance of 70 s/m.

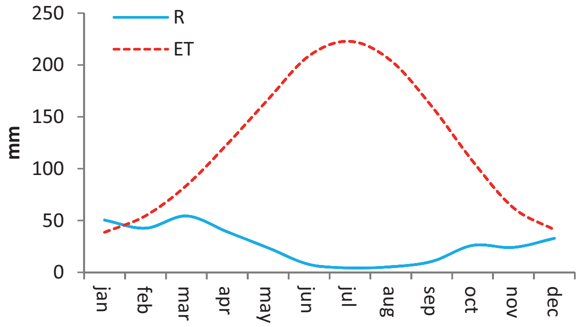

Figure 2 Monthly rainfall (*R*) and potential evapotranspiration (PET) in Class 1.

(100) are considered high potential high risk periods for the incidence of fascioliasis disease [6]. For the fascioliasis outbreak risk maps, the seasonally summated Mt values were grouped into 4 risk categories, which are shown in Table 1, according to Ollerenshaw and Rowlands [9] seasonal Mt value.

Results

The fascioliasis outbreak risk map for the whole country was developed using the Ollerenshaw risk model (Fig. 1). We found that the country can be divided into 4 classes (C1—C4) based on the risk of fascioliasis outbreaks. The first class (C1), in which the seasonal Mt value is less than 300, includes more than 0.91 of the country's area. The climate in this class is not conducive to fascioliasis incidence. Dryness and low temperature in the wet season (December to April) are the key barriers against fascioliasis outbreaks in this class. In large parts of C1, including the southern and central provinces, such as Isfahan, Yazd, Sistan and Balouchestan, Kerman, Semnan and Khorasan, the mean annual rainfall is less than 100 mm. The aridity and lack of freshwater affect the local distribution of intermediate snail host populations and are the most important limitations to disease outbreak. In the northern and north western areas of this Class (C1), including Koredestan, Kermansha and W&E Azarbayejan provinces, the mean annual rainfall is approximately 400 mm while the average temperature of the rainy season is approximately 4 °C, which is lower than the outbreak threshold. In the western and northwestern areas of C1, the seasonal Mt value is approximately 280, but it still does not exceed the outbreak threshold (300). The difference between monthly rainfall (*R*) and potential evapotranspiration (PET) as an index of aridity is depicted in Fig. 2. As seen in Fig. 2, the PET is greater than *R* in all months. The second and third classes

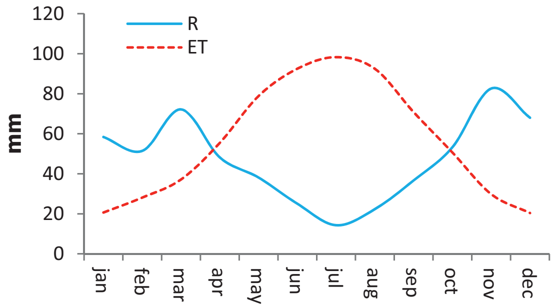

Figure 3 Monthly rainfall (*R*) and potential evapotranspiration (PET) in Class 2 and 3.

(C2 and C3), including the common provinces (Western part of Gilan, Ardabil, a small part of Isfahan, Charmahalobakhtiari, Kohkiloyeo, Boirahmad, Mazandaran), have the same fascioliasis outbreak risk level. In these classes, fascioliasis in the livestock population has been frequently observed. Surveys of slaughters in Mazandaran, Chaharmahal bakhtiari and Ardabil provinces indicated that the fascioliasis incidence rate is approximately 0.03—0.12 among slaughtered sheep and cows. As seen in Fig. 3, the monthly PET in the mentioned classes is higher than *R* from April to October (7 months in year). The risk map based on climatic factors indicated that only 0.03 of the country, including Gilan province in northern Iran is highly suitable for fascioliasis outbreaks from August to January. The Mt value is higher than 500 in this class (C4). Heavy rainfall in the summer and fall, especially in Rasht, Astara and Bandar Anzaly (>1000 mm/year), creates more suitable breeding places for snail intermediate hosts by reducing the salinity of its habitats. As shown in Fig. 4, the monthly *R* is higher than PET in all months except July and June (summer). As seen in Fig. 5, from September to March, the monthly Mt value in Gilan province is greater than the threshold value (100). Bandar Anzali (Anzali port), located in the west of Gilan province, has the highest monthly Mt value in Gilan.

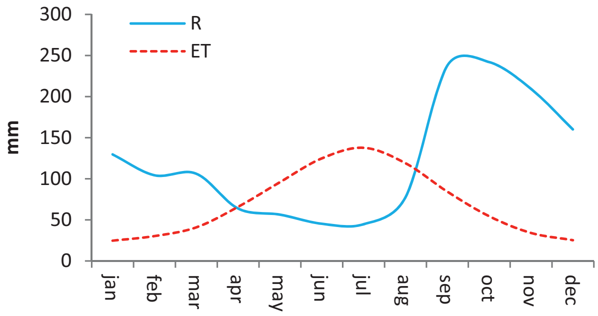

Figure 4 Monthly rainfall (*R*) and potential evapotranspiration (PET) in Class 4.

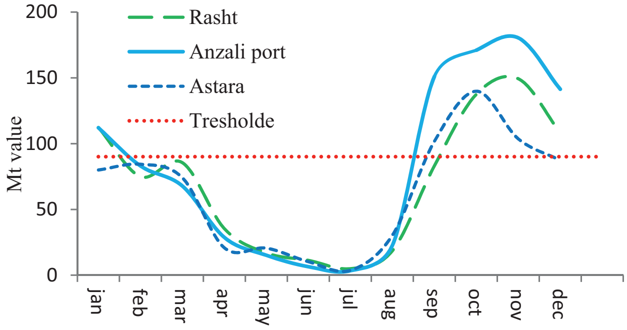

Figure 5 Monthly Mt value in high risk class (C4).

Discussion

According to the developed fascioliasis risk map, depending upon the interaction between monthly rainfall and potential evapotranspiration, only Gilan province is highly susceptible to fascioliasis outbreaks. The first fascioliasis epidemic, and the largest in the world, occurred in Gilan starting in February, 1988. The total number of infected inhabitants was estimated to be between 9008 and 20,000 people [18,19]. A second outbreak occurred some 10 years later (1999) and, again, several thousand people were infected in Gilan and Bandar-Anzali in the Caspian Sea region. The number of infected cases in this epidemic was estimated to be 2465 people. Gilan province is located along the shores of the Caspian Sea with an altitude from between 15 m below sea level to 300 m above it. Wetlands and paddy rice field make up 60% of Gilan land-cover. The climate of the province is characterized by precipitation of 1300—1800 mm yearly. In addition, the mean temperature is between 7 and 25.5 °C, and the potential evapotranspiration is between 15 and 133 mm. Several hundred cases have been recorded annually, between the two epidemics and afterwards, by the health centers of Rasht and Bandar-Anzali, indicating the endemicity of the disease and its public health importance in northern Iran. In the endemic areas of Gilan, there are several types of wild grown plants (*Eryngium* spp. and *Mentha* spp.), which are very popular and may be eaten fresh or ground and mixed with walnuts, various spices, garlic and fresh olives for the preparation of an appetizer called Zeitoon-Parvardeh or may be used along with a great quantity of salt for the preparation of a herbal paste called Delaro. The aromatic vegetables, considered by previous workers as the main source of human infections in this area, are collected by villagers and sold in the streets almost thorough the year [15].

Conclusions

In this study, we developed a climate based risk map of fascioliasis outbreaks in Iran using the Ollerenshaw risk model. We found that dryness and low temperatures in the rainy season (December to April) are the key barriers against fascioliasis outbreaks in more than 0.91 of the country's area. The developed risk map dependent on climatic factors indicates that only 0.03 of the country's area, including Gilan province in northern Iran, is highly suitable for fascioliasis outbreaks from August to January. We believe that investigations on fascioliasis outbreak characteristics should be conducted based on physiographical and climatic factors rather than on a country and province level.

Funding

No funding sources.

Competing interests

None declared.

Ethical approval

Not required.

References

[1] Reid JFS, Dargie JD. Como os estágios adultos de Fasciola hepatica afetam a saúde e a produtividade do bovino. Hora Vet 1995;15:23—6, http://dx.doi.org/10.1590/S1984-29612014003.
[2] Malek EA. Snail-transmitted parasitic diseases, vols. 1 and 2. Boca Raton, FL: CRC Press; 1980, 334 pp., 324 pp.

[3] Boray JC. Fascioliasis. In: Hillyer GV, Hopla CE, editors. Handbook series in zoonoses, section C. Parasitic zoonoses, vol. 3. Boca Raton, FL: CRC Press; 1982. p. 71—88.

[4] McCann CM, Baylis M, Williams DJL. The development of linear regression models using environmental variables to explain the spatial distribution of *Fasciola hepatica* infection in dairy herds in England and Wales. Int J Parasitol 2010;40(9):1021—8, http://dx.doi.org/10.1016/j.ijpara.2010.02.009 [Epub 2010 Mar 12].

[5] Martins IV, de Avelar BR, Salim Pereira MJ, da Fonseca AH. Application of a geographical information system approach for risk analysis of Fascioliasis in southern Espírito Santo state, Brazil. Geospat Health 2012;6:87—93, http://dx.doi.org/10.4081/gh.2012.126.

[6] Fox NJ, White PCL, McClean CJ, Marion G, Evans A, Hutchings MR, et al. Predicting impacts of climate change on *Fasciola hepatica* risk. PLoS ONE 2011;6:e16126, http://dx.doi.org/10.1371/journal.pone.0016126. PMCID: PMC3018428.

[7] The National Animal Disease Information Service website. http://www.nadis.org.uk [accessed 2013].

[8] Gettinby G, Hope-Cawdery MJ, Grainger JNR. Forecasting the incidence of fascioliasis from climate data. Int J Biometeorol 1974;18(4):319—23.

[9] Ollerenshaw CB, Rowlands WT. A method of forecasting the incidence of fascioliasis in Anglesey. Vet Rec 1959;71:591—8.

[10] McIlroy SG, Goodall EA, Stewart DA, Taylor SM, McCracken RM. A computerized system for the accurate forecasting of the annual prevalence of fasciolosis. Prevent Vet Med 1990;9(1):27—35.

[11] Van Dijk J, David GP, Baird G, Morgan ER. Back to the future: developing hypotheses on the effects of climate change on ovine parasitic gastroenteritis from historical data. Vet Parasitol 2008;158:73—84, http://dx.doi.org/10.1016/j.vetpar.2008.08.006 [Epub 2008 Aug 22].

[12] Asrat M, Peden D, Jobre Y, Taddesse G, Abebe G, Gideyelew T. Evaluation of the spatial distribution of *Fasciola hepatica* and *Fasciola gigantica* using geographical information system (GIS) in the Nile River Basin, Ethiopia. Ethiopia Vet J 2007;11(2):41—57.

[13] Malone JB, Gommes R, Hansen J, Yilma JM, Slingenberg J, Snijders F, et al. A geographic information system on the potential distribution and abundance of *Fasciola hepatica* and *F. gigantica* in east Africa based on Food and Agriculture organisation databases. Vet Parasitol 1998;78:87—101.

[14] Sahba GH, Arfaa F, Farahmandian I, Jalai H. Animal fascioliasis in Khuzestan, Southwestern Iran. J Parasitol 1972;58:712—21.

[15] Ashrafi K, Valero MA, Forghan-Parast K, Rezaeian M, Shahtaheri SJ, Hadian MR, et al. Potential transmission of human fascioliasis through traditional local foods, in Northern Iran. Iran J Publ Health 2006;35.

[16] Mas-Coma S, Valero MA, Bargues MD. Climate change effects on trematodiases, with emphasis on zoonotic fascioliasis and schistosomiasis. Vet Parasitol 2009;163:264—80, http://dx.doi.org/10.1016/S0065-308X(09)69002-3.

[17] Ollerenshaw CB. A comment on the epidemiology of *Fasciola hepatica* in Italy. Ann Fac Med Vet Torino 1973;20:83—121.

[18] Salahi-Moghaddam A, Habibi-Nokhandam M, Fuentes MV. Low-altitude outbreaks of human fascioliasis related with summer rainfall in Gilan province, Iran. Geospat Health 2011;6(1):133—6, http://dx.doi.org/10.4081/gh.2011.165.

[19] Salahi-Moghaddam A, Fereydoun A. Epidemiology of human fascioliasis outbreaks in Iran. J Arch Mil Med 2013;1:6—12.