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Cutaneous leishmaniasis prevalence and morbidity based on environmental factors in Ilam, Iran: Spatial analysis and land use regression models

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ABSTRACT

The aim of this study was to investigate the impact of the environmental factors on cutaneous leishmaniasis (CL) prevalence and morbidity in Ilam province, western Iran, as a known endemic area for this disease. Accurate locations of 3237 CL patients diagnosed from 2013 to 2015, their demographic information, and data of 17 potentially predictive environmental variables (PPEVs) were prepared to be used in Geographic Information System (GIS) and Land-Use Regression (LUR) analysis. The prevalence, risk, and predictive risk maps were provided using Inverse Distance Weighting (IDW) model in GIS software. Regression analysis was used to determine how environmental variables affect on CL prevalence. All maps and regression models were developed based on the annual and three-year average of the CL prevalence. The results showed that there was statistically significant relationship (*P* value $\leq$ 0.05) between CL prevalence and 11 (64%) PPEVs which were elevation, population, rainfall, temperature, urban land use, poorland, dry farming, inceptisol and aridisol soils, and forest and irrigated lands. The highest probability of the CL prevalence was predicted in the west of the study area and frontier with Iraq. An inverse relationship was found between CL prevalence and environmental factors, including elevation, covering soil, rainfall, agricultural irrigation, and elevation while this relation was positive for temperature, urban land use, and population density. Environmental factors were found to be an important predictive variables for CL prevalence and should be considered in management strategies for CL control.

1. Introduction

Cutaneous leishmaniasis (CL) is a zoonotic disease with rodents as the reservoirs and female phlebotomine sand fly as a vector. Approximately 90% of the total Leishmaniasis occur in eight countries of the world, including Iran (Doudi, 2011). In Iran, Leishmaniasis is mostly found as the zoonotic CL type (Salah et al., 2007). Leishmaniasis is a multi-reservoir disease and due to the reservoirs dependency on the environmental conditions, the distribution of the disease can be associated with the environmental factors such as temperature, humidity, rainfall, and land use (Ali-Akbarpour et al., 2012; Cortes et al., 2012; Salah et al., 2007).

According to the statistical analyses, the distribution of CL has shown a negative correlation with relative humidity and a positive correlation with annual rainfall (Salah et al., 2007; Salahi-Moghaddam et al., 2015).

GIS and regression models have been widely used in CL studies. In France, Land-Use Regression (LUR) method was applied to assess the impact of the environmental conditions on the distribution of CL in areas with a Mediterranean climate in order to predict the probability of CL incidence in selected areas and to create a predictive risk map of CL prevalence using Geographic Information System (GIS) (Chamaillé et al., 2010). In India, predictive risk map generated by GIS revealed that the density of sand flies infected with Leishmania was higher in areas around the swamps and near the rooted

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trees and sugarcane plantation (Bhunia et al., 2012; Sudhakar et al., 2006).

The most popular model in GIS is IDW by which spatial distribution of the disease can be provided. In the IDW method, the weights of the data are inverse function of the distance between data points. An exponent of the distance has to take values greater than zero. For instance, a value of 2 would mean that the data are inversely weighted as the square of the distance (Gumiere et al., 2014; Webster and Oliver, 2007). The IDW method is deterministic and shows no discontinuities when the weighting exponent is greater than zero. However, weighting exponent selecting is somewhat arbitrary and the IDW method does not take into account the configuration of the sampling scheme (Webster and Oliver, 2007). IDW method has been widely used to determine the spatial distribution of LC and other diseases (Bhunia et al., 2013; das Chagas Xavier et al., 2012; Hanafi-Bojd et al., 2012; Ryan et al., 2006; Shirzadi et al., 2015).

Simultaneous use of the regression models and GIS can be critical for CL control by which the spatial distribution are determined and the risk prone areas to be infected in the future are predicted (Bavia et al., 2005). According to various published information regarding sand flies, a digital database providing and transmission modeling and predicting across the countries can help the health authorities to make more correct and prompt decisions in planning for leishmaniasis control (Karimi et al., 2014).

LUR is a combination of GIS and regression analysis in which raw data are firstly prepared by statistical methods and then used in GIS to create the spatial map. LUR model provides useful local information about the distribution of the diseases and environmental pollutants for the users and decision makers (Chamaillé et al., 2010; Salahi-Moghaddam et al., 2015). This model can be developed based on the meteorological and environmental factors such as temperature, wind direction, rainfall, and land use type (Bhunia et al., 2013; Hoek et al., 2008; Liu et al., 2015).

Therefore, with respect the above, this study was aimed to cover the followings:

- Investigation of CL prevalence and morbidity in the study area and spatial analysis of CL prevalence based on IDW method.
- Investigation of the role and proportion of PPEVs in the distribution and prevalence of CL disease in the study area.
- Developing a LUR model in the study area by which the impact of the PPEVs on disease distribution is determined and the risk map of disease at present and in the future is created.

The results of the present study can be used to determine the proportion of environmental factors on CL transmission. This may facilitate the interventions in CL control which has shown an increasing growth in recent years. Also the predictive risk map of the prevalence may help to select the low risk areas for the development of new cities, villages, and habitations and settlement of military and non-military camps in the frontier and remote regions.

2. Materials and methods

2.1. Study area

Ilam province is located in western Iran with a population of about 557,599 and a total surface area of 20133 km^2. It is situated between 45°24′ and 48°10′ longitude, and 31°58′ and 34°15′ latitude sharing a land border with Iraq. This province is recognized as one of the endemic areas of CL in the Middle East (Nejati et al., 2014). Fig. 1 shows the location of this province in Iran and the Middle East. The climate varies from cold semi-humid in the north to hot desert in the south of the province. Average annual rainfall is 520 mm in northern areas and 150 mm in southern areas. In northern areas, mainly in the mountains, lands are covered by semi-forest (Oak forest), while the southern areas are mainly desert and semi-desert. Around the villages, there are mostly barren land, dry farming, and irrigation lands (Arekhi et al., 2010). Topsoil is predominantly covered with gypsum, limestone, clay, or a combination of them (Ali-Akbarpour et al., 2012). The province was considered as a war area for eight years after Iraq attack on Iran in 1981. Lack of appropriate health services during the war years, displacement of Iran and Iraq military forces, and the environmental conditions along with other related factors have accelerated the prevalence of some contagious diseases such as CL in this area (Nejati et al., 2014).

2.2. Collection and preparation of leishmaniasis data

The statistical information and exact postal addresses of CL patients who had referred to 64 health centers (as is illustrated in Fig. 1) from 2013 to 2015 were collected. Since the signs of CL develop almost two months after sand fly bite (Ali-Akbarpour et al., 2012; Salahi-Moghaddam et al., 2015; Yoosefi and Vakil, 2007); therefore, the time of the biting was used in data analysis in order to assess the role of the environmental variables on disease. Based on the postal addresses, accurate geometric locations of patients were specified in terms of latitude and longitude at the Universal Transverse Mercator system. A mobile GPS device (eTrex 20 Garmin, USA) was used for recording the Latitude (Y) and Longitude (X) of the locations. The accurate locations of 3237 CL patients were prepared to be used in GIS. CL data were also generated to be applied in LUR examinations for determining the annual and the three-year average morbidities.

2.3. Generation of spatial predictors

In this study the environmental variables affecting the prevalence of CL were recognized and after separation of the areas according to the type of the effective variables, the association between each variable and the prevalence of CL was determined using GIS. Regression equations were generated between the sorted variables and the prevalence of CL. These equations which were derived from the current status of the infected areas were used to map the risk of prevalence in other spots. For this purpose, with regard to previous studies (Ali-Akbarpour et al., 2012; Chamaillé et al., 2010; Chaves and Pascual, 2006; Desjeux, 2001; Elnaiem et al., 2003; King et al., 2004; Reithinger et al., 2007; Salah et al., 2007; Sudhakar et al., 2006; Weigle et al., 1993), 17 PPEVs in six classes with probable impact on CL prevalence were investigated (Table 1). The six classes included temperature, rainfall, population, type of soil (3 variables), land use (6 variables), and elevation. Considering the flight range of the sand fly as the vector of the disease as well as the motion range of the rat as the main reservoir of CL, two buffer zones were drawn with radii of 500 (the highest influence) and 1000 m (the least influence) around the prevalence area for nine predictive variables whose their types and amounts were expected to be changed in distances more than 500 m (Table 1). Previous studies had reported the activity distance of sand flies and rats from 500 to 1000 m (Nejati et al., 2014; Yoosefi and Vakil, 2007). For three PPEVs of temperature, rainfall, and elevation which did not change much with low distance, altitude lines of isotherm, isohyet, and isohypse were used instead of radial area. The digital data of the present study were the vector type taken from related organizations. Temperature and precipitation data were provided based on an annual mean precipitation map prepared by the province Meteorological Organization. The population density of each region was based on the population maps provided by the Ilam Governor. Soil type map, DEM layer, and land use map were taken from the