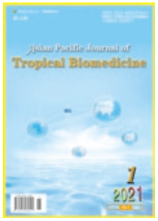

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Identification of climatic and environmental factors associated with incidence of cutaneous leishmaniasis in Central Iran using satellite imagery

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ABSTRACT

Objective: To determine the effect of climatic and environmental factors on the incidence of cutaneous leishmaniasis in Qom province in 2018.

Methods: In this cross-sectional study, the data on cutaneous leishmaniasis incidence were collected from the Disease Control and Prevention Center in Qom province. Climatic and environmental data including Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and soil moisture were extracted using satellite images. Data of altitude and sunny hours were provided based on shuttle radar topography mission digital elevation model and hemispherical viewshed algorithm, respectively. The associations of climatic and environmental variables with the incidence of the disease were analyzed by Pearson correlation method. The ArcGIS 10.3 software was used to determine the geographical distribution of these factors.

Results: There were positive correlations between cutaneous leishmaniasis incidence and the two climatic factors: LST and sunny hours per day (P=0.041, P=0.016), and it had weak negative correlations with the digital elevation model (P=0.27), soil moisture (P=0.54), and NDVI (P=0.62). The time delay analysis showed that in one-, two-, and three month periods, the correlations increased with a 95% confidence interval. Accordingly, the correlation with the three-month time delay was positive and relatively strong between the cutaneous leishmaniasis incidence and LST and sunny hours (P=0.027, P=0.02); nevertheless, there were negative correlations between the cutaneous leishmaniasis incidence and the soil moisture (P=0.27) and NDVI (P=0.62).

Conclusions: As Qom is located in one of the semi-arid climate zones, topography and solar energy are important factors affecting the incidence of cutaneous leishmaniasis in autumn. Therefore, appropriate disease control programs are recommended.

KEYWORDS: Environmental factors; Incidence; Satellite imagery; Cutaneous leishmaniasis; Iran

1. Introduction

Cutaneous leishmaniasis (CL) is considered as an emerging infectious skin disease[1]. Some species of *Leishmania* Ross (Kinetoplastida, Trypanosomatidae) parasites are the causative agents of the infection and wild rodents are known as the main reservoir hosts[2]. This vector-borne disease is transmitted to humans by the bite of some infected female phlebotomine sand fly species[3]. The economic and social burden of the disease is not associated with high mortality, but the high incidence, tissue damages and skin lesions in patients are considerable[4].

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The leishmaniasis is an endemic disease in 102 countries in five continents[5]. The most prevalent endemic foci of CL are reported from Afghanistan, Algeria, Brazil, Colombia, Iran, and Syria[6]. In recent years, the annual new cases of CL in endemic foci in Iran are estimated to be 20 000 to 30 000 cases. The disease is reported from different climatic and environmental situations[7]. The prevalence of CL in various areas of the country does not have a logical distribution pattern. The highest incidence rate in Iran was recorded in arid and semi-arid regions and foothills, such as Yazd, Bushehr, Khorasan, Fars, Ilam, Khuzestan, and Isfahan provinces with the mean incidence rate of 166 per 100 000 people[8]. The mountainous areas of the country such as western and northwestern provinces have the lowest incidence of CL (lower than 10 per 100 000 people)[8].

Although economic, social and cultural factors are associated with the prevalence of CL, climatic factors are usually considered as more effective and main determinants in the distribution of CL vectors and the incidence rate of the disease[9]. Regarding leishmaniasis cycle, climatic, environmental, and ecological factors are mentioned as critical[10]. Several previous studies conducted on the role of climatic and environmental factors in the incidence of CL have shown that some factors such as temperature, and humidity have effects on the development of sand flies as CL vectors[10,11]. Previous researches have shown that the relative humidity and temperature ranges for the development of sand flies have been estimated to be 80%-90% and 21-29 ℃, respectively[12,13]. Likewise, it has been proved that in addition to ecological conditions, those areas with a desert climate, soft soil texture, and hot/dry weather are essential for the development of wild rodents as the main reservoirs of CL[14]. Qom province is one of the active foci of CL in Iran. Recently, it is reported that the incidence rate of CL in Qom province was 14.2 per 100 000 people in 2017[15]. In this province, the climatic and environmental conditions are different in different districts, and these conditions seem to affect the three main components related to the transmission cycle of CL: vectors (phlebotominae sand flies), reservoirs (such as wild rodents), and parasite. Therefore, the aim of this study was to determine the impact of climatic and environmental factors on the incidence of CL in Qom province, central Iran by satellite imagery.

2. Materials and methods

2.1. Study sites

Qom province in central Iran is one of the main foci of CL and the distribution area of phlebotomine sand flies[16,17]. It is one of the 31 provinces of Iran with 11 237 km^2, covering 0.89% of the total area, located in the center of the country. The province population is 1 151 672 in which 95.2% of people reside in urban areas and 4.8% live in rural areas. Qom province has one city, 5 districts, and 258 villages. This province has two types of climate zones, namly the desert climate including Markazi, Salafchegan, Jafar abad districts and semi-arid climate including Khalajestan and Kahak districts. It is located near the central desert of Iran with an altitude of 900-1 500 m above sea level. Plains of the province extend to the central desert with a gentle slope from west to east. The study area has the annual precipitation of 215-125 mm and 43 freezing days per year.

2.2. Data collection

Firstly, the data about 184 confirmed CL cases in 2018 were collected from the Disease Control and Prevention Center of Qom University of Medical Sciences. Statistical units in this study were based on city and district. The climate and environmental variables were extracted using satellite images. Altitude was extracted based on shuttle radar topography mission digital elevation model (DEM) with spatial resolutions 90 m. Moreover, hemispherical viewshed algorithm was used to calculate sunny hours. In this method, the sum of sunny hours is calculated based on DEM[18]. DEM with fixed coordinate as an inevitable component in the field of remote sensing and GIS reflects the physical surface of the earth which helps to understand the nature of the earth. In order to study the spatial distribution of the vegetation, the normalized difference vegetation index (NDVI) was used based on the difference between near-infrared and red bands. The value of NDVI varies between −1.0 and + 1.0. The positive NDVI value indicates the increase in the amounts of green vegetation. The characteristics of images about other parameters such as vegetation, Land Surface Temperature (LST), and soil moisture were provided from https://giovanni.gsfc.nasa.gov/giovanni/ and shown in Table 1.

2.3. Statistical analysis

The incidence of CL disease was calculated for each district and village after encoding. Spatial distribution maps and incidence of CL in Qom province were separately extracted using the incidence rates in each district. The seasonal activity of sandflies as vectors of this disease depends on environmental and climatic conditions. Since the peak activity of sandflies in the study area was focused on three months from July to September, the relationship between climatic/environmental factors and the incidence of the disease was dertermined. Pearson Correlation Coefficient in SPSS version 23.0 was used.

2.4. Ethical statement

This study was under the supervision of Qom University of Medical Sciences, Qom, Iran, with the approval of the Ethics Committee under the code of IR.MUQ.REC. 1396.68.

Table 1. Data, methods and algorithms used to extract climatic and environmental indicators.

Climatic and environmental factors	Source	Unit	Spatial resolutions	Temporal resolution
Vegetation (NDVI)	MODIS-Terra	NDVI	0.05°	Monthly
Land Surface Temperature	MODIS-Aqua	℃	0.05°	Monthly
Digital elevation model	SRTM	Meter	90 m	-
Soil moisture	GLDAS Model	Kg/m^2	0.25°	Monthly
Sunny hours	DEM (SRTM)	Hours	90 m	-

MODIS: Moderate Resolution Imaging Spectroradiometer; GLDAS: Global Land Data Assimilation System; SRTM: shuttle radar topography mission; DEM: digital elevation model; NDVI: normalized difference vegetation index.

3. Results

3.1. Incidence of CL

The incidence of CL in Qom province was 14.2/100 000 people (184 cases per 1 292 000 population). Although CL disease was recorded from all districts of the province, the spatial variation maps of the disease indicate that Markazi district had the highest incidence of CL compared to other areas (69.91/100 000 people), while Kahak district had the lowest incidence (4.85/100 000 people). The distribution of CL patients in other areas of the province is shown in Figure 1A. Additionally, based on the results of geographic and zoning distribution studies, *Meriones libycus* (Rodentia: Muridae) was the CL reservoir host in Markazi, Kahak districts, and Qom city of Qom province. Besides, the presence of *Phlebotomus papatasi* (*P. papatasi*) (Diptera: Psychodidae) as the main vector of CL was reported in most districts of the province, and its contamination with *Leishmania major* was also confirmed in Markazi and Kahak districts (Figure 1B and C).

3.2. Climate condition

As shown in Figure 2A, the northern and eastern parts of the province had poor vegetation from October to December. Spatial maps show lower temperatures in the salt-lake and Qom city in comparison to their adjacent regions. The central areas (Qom city) of the province had richer vegetation and lower temperature, similar to the southern and western regions that had the lowest temperature because of higher altitudes (Figure 2B). The average height of Qom province is approximately 930 meters above sea level, reaching 762 meters at the lowest point, near the desert part (Markazi district), and 3 192 meters at the highest point, in the mountains of the southern and eastern regions. Such a height variation for a province, which is not so vast and spacious, creates a special environmental and climate condition for this province (Figure 2C). The spatial variability of surface soil moisture showed that the southern and western parts of the study area had relatively higher altitudes and richer vegetation. In other parts, the northern and eastern areas, low humidity was seen except for the water levels (Figure 2D). The spatial variations of the total sunny hours in the north were greater than the southern and western parts because of the altitude difference and ground roughness of the southern and western areas (Figure 2E).

Average data on environmental and climatic parameters was calculated, using Arc Zone's ArcGIS software, for all districts from July to September (Figure 3). The results showed that the highest CL incidence was observed in Markazi district in Qom province. This area had poor vegetation and soil moisture, despite being near to water zones. It also had a higher temperature (mean temperature of Markazi district was 27.50℃), total sunny hours, and also the highest salinity with the lowest altitude in the province. Moreover, a considerably high CL incidence was also reported in Jafar abad district. This area had richer vegetation, higher temperature (24.62℃), and sunnier hours (871.82 hours) along with a lower DEM with the average of 1 035.44 m above sea level. The incidence of the disease in Salafchegan district was 60.37 per 100 000 people, the third highest incidence after Markazi and Jafar abad districts. This district exhibited moderate climate indicators in comparison to the other districts. Khalajestan and Kahak districts had the lowest incidence of CL, 13.87 and 4.85

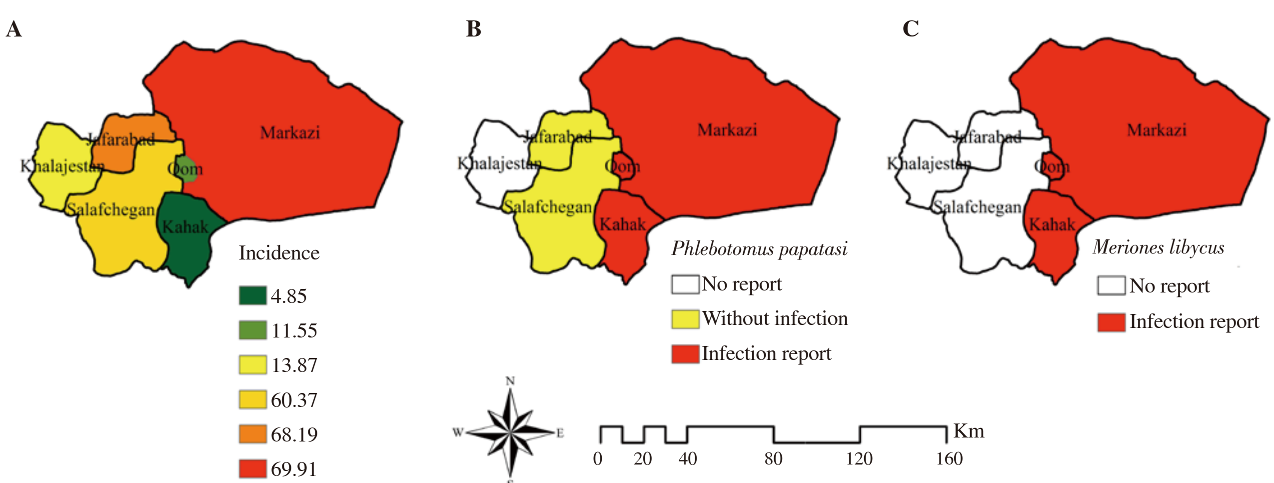

Figure 1. Incidence of cutaneous leishmaniasis (A) and spatial distribution of its main vector (B) and reservoir (C) in Qom Province, Central Iran, 2018.

per 100 000 people, respectively. Both districts were the highest regions in the province with same sunny hours. In contrast to Kahak district, Khalajestan showed a lower temperature with richer vegetation.

Table 2. Pearson correlation coefficient for environmental and climate factors related to cutaneous leishmaniasis in Qom province in 2018.

Indicator/Correlation coefficient	Soil moisture	NDVI	LST	Sunny hours	DEM
Autumn (September, August, July)	–0.75	–0.17	0.80	0.53	–0.56
September	–0.45	–0.22	0.86	0.55	-
August	–0.36	–0.26	0.81	0.53	-
July	–0.46	–0.35	0.80	0.49	-

3.3. The role of climatic elements in the incidence of cutaneous leishmaniasis

Pearson correlation was used to measure correlation between climatic parameters and CL incidence. There is a strong correlation between the incidence of CL and the sunny hours, and LST. Therefore, the incidence of the disease increased with the rise in the LST and sunny hours and fall with the lower DEM. In addition, based on the time delay analysis in one-, two-, and three month-periods, the correlations increased with a 95% confidence interval. Thus, the correlations with the three-month time delay, LST, and sunny hours were positive and relatively strong (P=0.027, r=0.86, P=0.02, r=0.54). However, there were strong negative correlations between the incidence of CL and soil moisture (P=0.27, r=–0.75) or vegetation (P=0.62, r=–0.26) (Tables 2 and 3).

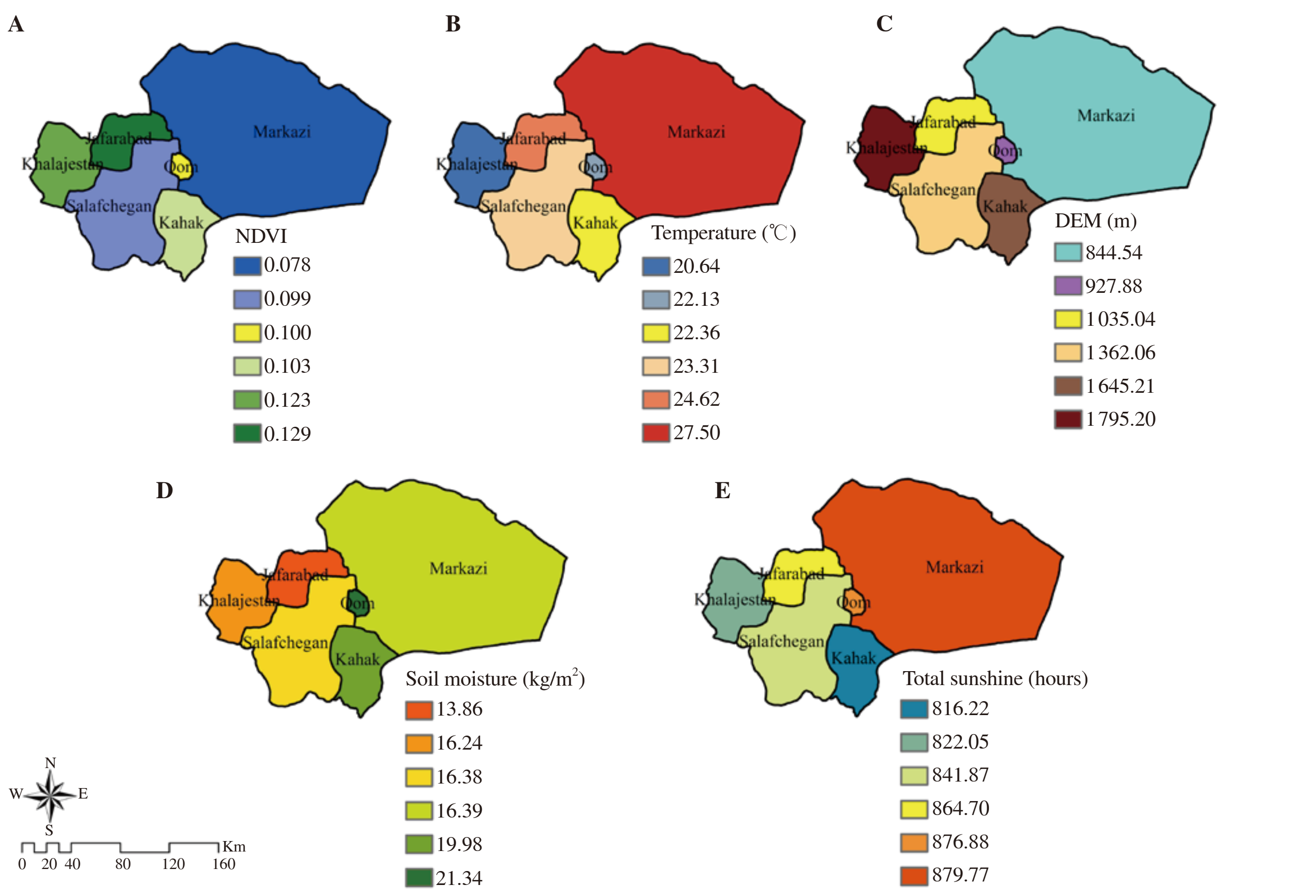

Figure 2. Geographical distribution of environmental and climate indicators in Qom province from October to December 2018. (A) NDVI; (B) Temperature; (C) DEM; (D) Soil moisture; (E) Total sunshine.

Table 3. Correlation coefficient with time delay between climatic and environmental factors and cutaneous leishmaniasis incidence in Qom Province in 2018.

Time series	NDVI	LST	Soil moisture	Sunny hours	DEM
	r^* (P value)	r (P value)	r (P value)	r (P value)	r (P value)
Three-months delay	–0.26 (0.62)	0.86 (0.027)	–0.54 (0.27)	0.54 (0.02)	-
Two-months delay	–0.37 (0.47)	0.82 (0.46)	–0.37 (0.47)	0.54 (0.02)	-
One-month delay	–0.26 (0.62)	0.81 (0.051)	–0.54 (0.27)	0.31 (0.04)	-
without delay	–0.18 (0.62)	0.81 (0.041)	–0.54 (0.27)	0.49 (0.016)	–0.56 (0.27)

*r: Values of the Pearson correlation.

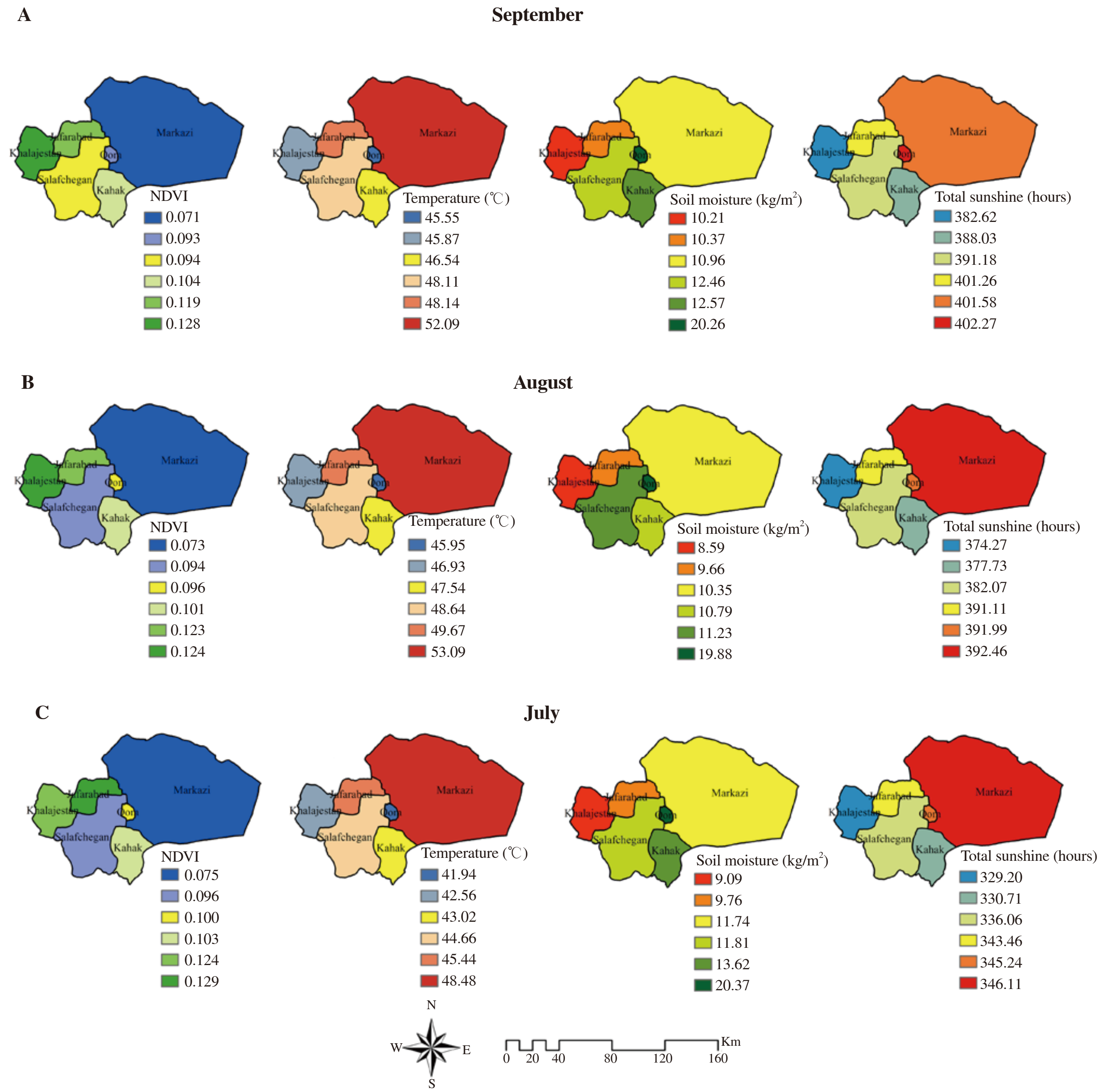

Figure 3. Average environmental and climate parameters in Qom province from July to September (A-C), 2018.

4. Discussion

The spatial and temporal changes in the incidence of CL disease in this study showed that the highest incidence of disease occurred in the autumn from October to November, in Markazi district of Qom province, while Kahak and Khalajestan districts had the lowest incidence. According to previous field studies, sand flies fauna of this area includes *P. papatasi*, *Phlebotomus sergenti*, *Phlebotomus alexandri*, *Phlebotomus caucasicus*, *Phlebotomus caucasicus* group (female), *Phlebotomus kandelakii*, *Phlebotomus tobbi*, *Phlebotomus major*, *Phlebotomus halepensis*, *Phlebotomus brevis*, *Phlebotomus adlerius* group, *Sergentomyia sintoni*, *Sergentomyia theodori* and *Sergentomyia pawlowski*. In addition, *P. papatasi* is the main vector of CL in several districts of Qom Province in central Iran[16,19]. Furthermore, the activity of phlebotomine sand flies in the central regions of Iran is usually from April to November, and their peak activity is in June and August. It means that the peak of CL incidence is seen with one or two months delay from the peak of sandflies activity[19]. This time delay logically happens in line with the disease common period (after the infected sand fly bite).

One of the probable reasons for the high incidence of CL in Markazi district may be the climatic condition and topography of the region. Markazi district of Qom province is located on a low plain and it has a hot desert climate, soft soil with poor vegetation. The soil surface has low moisture content, despite the water zones in this part. In addition, this district had higher LST and sunny hours than those of other districts. It seems that an increase in sunny hours in Markazi district can increase the agricultural products and provide the food resources for developing the wild rodents as the reservoir of the disese. Fourthermore, low moisture content of soil surface may lead to the formation of the breeding habitats for female sand flies[20]. Moreover, its low altitude makes it suitable for wild rodents to live as the main reservoirs of *Leishmania* parasite.

From the central parts to the west of the province, the mountainous and rocky areas provide unfavourable enviroment for the rodents to live and construct burrows under the ground. Therefore, in the western and southern regions of Qom province, Khalajestan district had the lowest number of CL cases that might have a history of travel to other endemic areas during the transition period. In many endemic foci of CL, especially in the central provinces of Iran, such as Isfahan, Semnan and Kerman, the climatic condition, geographical, and topographical features are very close to those in Markazi district of Qom province[21]. Similary, based on the findings of previous studies, *Meriones libycus* and *P. papatasi*, were reported to be contaminated with leishmaniasis as reservoir and vector of the disease in Qom province[16,22]. In addition, the rodent burrows are suitable for breeding and growing of sand flies as they have soft soil texture, suitable temperature, and required materials with no significant fluctuations[23]. On the other hand, in many previous studies, the vast majority of sand flies, including *P. papatasi*, were in rodent burrows[24,25].

In this study, the incidence of CL had the highest positive correlation coefficient with the sunny hours and LST. Therefore, the CL incidence increased with sunny hours and LST but decreased with DEM. In other previous studies, researchers have proved that temperture has effects on behavioral activities and the life cycle of sandflies as the vectors and wild rodents as reservoir hosts for *Leishmania* parasite transmision[26–28]. In this study, it was observed that the mean temperature of Markazi district of Qom province, having the highest rate of CL incidence, was 27.50 ℃ that corresponds the optimum temperature required for the development of sand flies as the disease vector (18-28 ℃). In Greek Aegean Islands, the optimum temperature for these vectors was reported as 21-29 ℃, which was relatively higher than that found in the present study[12,29]. In a study on CL in Isfahan province, central Iran, there were significant positive correlations of the CL incidence with the mean temperature, relative soil moisture, and the slope of the region[21]. Besides, the incidence of many communicable diseases, such as CL, is related to economic, social, and cultural factors as well as climate and environmental ones. Therefore, the lack of consideration about the impact of the socioeconomic factors on the incidence of this disease can be considered as a limitation of this study.

Overall, considering the fact that Qom province has a hot and dry climate in Iran, it can be concluded that topographic factors and solar energy amount are important features affecting the occurrence of CL in this region, specifically in the autumn season.

Conflict of interest statement

The authors declare that there is no conflict of interest.

Acknowledgments

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Authors' contributions

MJ and AS contributed to the work and data collection. Data analysis and interpretation were performed by MJ, AS, KE and AH. Drafting the article was done by AS, MJ, LZF and NS. Critical revision of the article was done by AS and MJ. The final approval of the version to be published was performed by all of the authors.

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