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ORIGINAL ARTICLE

Spatio-temporal analysis and determination of the ecological niche model of *Giardia Lamblia* (Lambl, 1859) in Ardabil province, northwestern Iran

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Abstract Intestinal parasites have a serious health problem and frequently infect children in poor urban areas in developing countries. Some types of Cryptosporidium, Entamoeba and Giardia are amongst the most prevalent ones. The aim of this study was explore the distribution pattern of intestinal parasites and the ecological niche of *Giardia lamblia* in Ardabil Province. This was retrospective cross-sectional study, the officially registered statistics of health centers and hospitals in Ardabil University of Medical Sciences from January 2017 to December 2019 were used. The Kriging interpolation analysis was run to detect the high-risk areas of the disease in the province ($P < 0.05$) by ArcGIS10.4.1 and to construct the ecological niche model of the *G.lamblia* parasite, analyzed by Maxent3.3 software. Totally of 238 cases of intestinal parasite were reported during the study period, 77.7% of which were males and 22.3% females. Seven types of intestinal parasites were prevalent with *G.lamblia* species (79.4%) being the most and *Entamoeba histolytica* species (4%) the least prevalent one. There was one hotspot in the province in the center with an incidence risk of 41–45.5%. The most important climate and environmental factors affecting the ecological niche of *G.lamblia* are Bio16, Bio3, and the NDVI. *G.lamblia* is the most prevalent intestinal parasite in Ardabil Province; moreover, one important hotspots was also detected in the province that can provide useful information regarding the management and control of this parasite.

Keywords *Giardia lamblia* · Ecological niche · Epidemiology · Iran

Introduction

Intestinal parasites have been considered a serious health problem around the world, especially in developing countries (Molina et al. 2011). Nowadays, although enormous costs are paid every year by the World Health Organization (WHO) and governments to eradicate, prevent and cure diseases associated with such parasites, they are still extant in the environment (Lafferty et al. 2006). Intestinal parasites frequently infect children in poor urban areas and developing countries. A wide range of worms and protozoans can cause infection or become colonized in animal and human digestive systems (Wells et al. 2018). These organisms are usually transmitted indirectly via the oral-fecal route by contaminated food, water and dust; nevertheless, a direct human-to-human and animal-to-human transmission have been also reported (Zajac and Conboy 2012).

Of various types of intestinal parasites widespread in the world, Cryptosporidium, Entamoeba and Giardia are amongst the most prevalent ones. For instance, after rotaviruses, cryptosporidium is the most important cause of diarrhea-related death among 5-year-old and younger children living in the southern areas of the Sahara Desert (Marchiondo et al. 2013). Likewise, aggressive amoebic infection resulting from *Entamoeba histolytica* infects more than 50 million people every year around the world and perishes around 100,000 people annually. It is also

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estimated that more than 200 million people contract marked giardia every year (Alwan 2011; Hegazi 2013). Other types of parasitic infections such as *Blastocystis hominis* and *Dientamoeba fragilis* have been also found to be more prevalent among people, especially those with no symptoms. The most prevalent types of intestinal worms in humans are soil-borne nematodes (e.g. *Ascaris lumbricoides*, *Trichuris trichiura*, *Ancylostoma duodenale*, *Necator americanus* and *Estrongiloidiasis stercoralis*) and cestoda (Taeniidae family) (Castillo and Vovlas 2007).

According to epidemiological studies conducted in Iran, the most prevalent kind of intestinal parasite in Iran is *B.hominis* followed by *G.lamblia* and *E. coli* (Kuzehkanani et al. 2011; Niyyati et al. 2009). The results of relevant studies show that the prevalence of intestinal parasites is 61% in the studied populations (Hemmati et al. 2017). Because Iran is a very diverse country in terms of climate conditions and consists of various socio-cultural patterns, there are different intestinal parasite distribution patterns in this country. Thus, knowing the ecological niche can show parasites' suitable habitat based on which human infections can be recognized. Moreover, based on the distribution and biological patterns of significant parasites, we can embark on appropriate preventive and treatment programs. Given that no ecological niche study has been conducted in Ardabil Province and the distribution pattern of prevalent parasites has not been investigated in this area of Iran, in this study, we aimed to explore the distribution pattern of intestinal parasites and the ecological niche of *giardia lamblia* in Ardabil Province.

Materials and methods

This study was carried out in Ardabil Province located in the northwest of Iran (38.4853°N, 47.8911°E). Ardabil Province covers an area of 17.953 km^2 (about 1.09% of the whole area of Iran) and is located on an open plain 1.338 m above sea level. According to the latest consensus in 2017, Ardabil Province has a population of 249,000 people. This province shares a border with the Republic of Azerbaijan from the north, with Gilan Province from the east, with the East Azerbaijan Province from the east and with Zanjan Province from the south (Fig. 1).

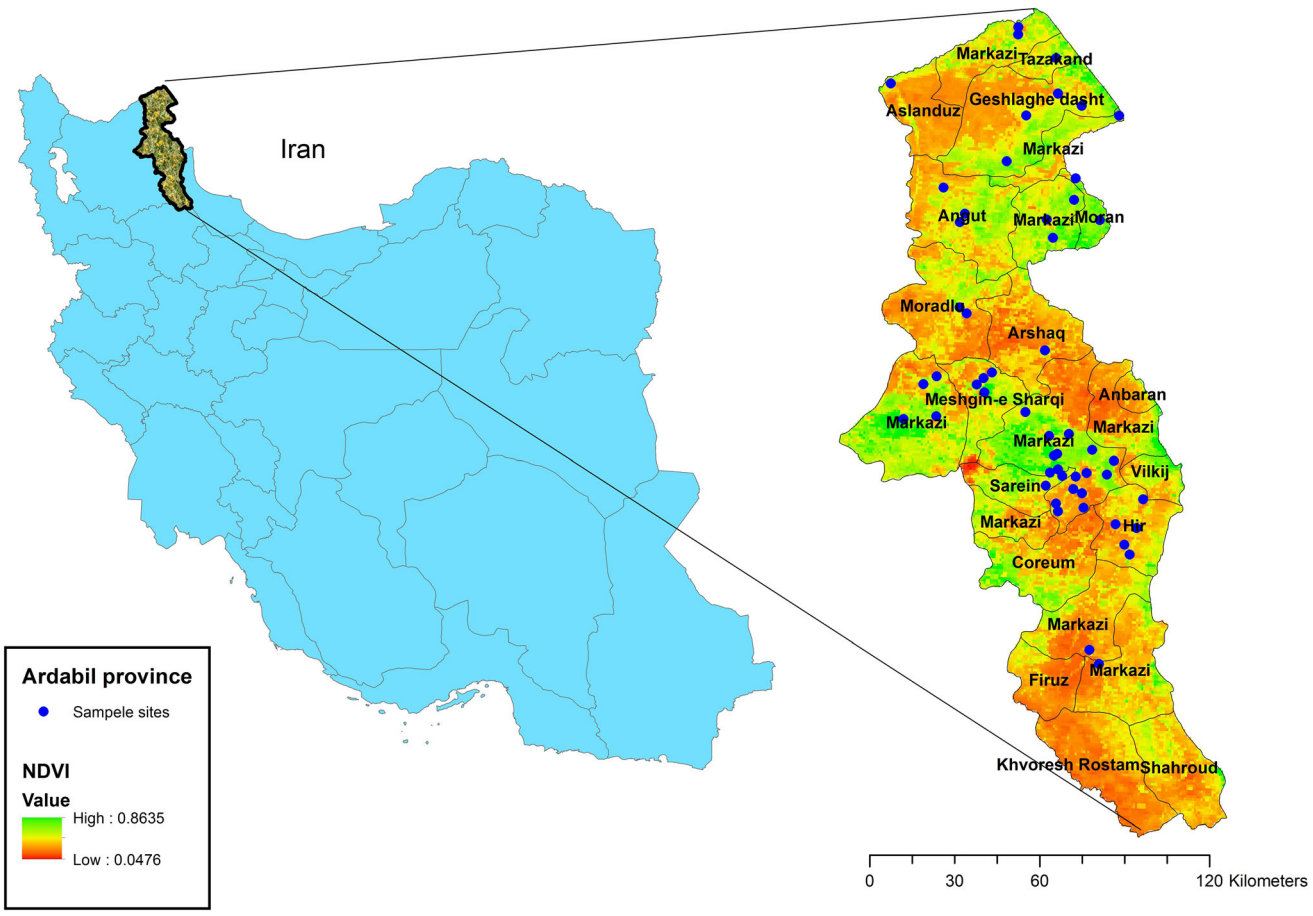


Fig. 1 Sampling locations and reporting sites for Giardia lamblia in the study area, Ardabil province, northwest of Iran, 2020

Data collection procedure

In this retrospective cross-sectional study, the officially registered statistics of health centers and hospitals in Ardabil University of Medical Sciences from January 2017 to December 2019 were used. The patients' information regarding age, sex and their living place was extracted and studied.

Table 1 Variables used for MaxEnt modeling of *Giardia Lamblia* distribution in Ardabil Province, Northwest of Iran

Spices	Male (%)	Female (%)	Total (%)
Ascaris lumbricoides	4 (66.67)	2 (33.33)	6 (100)
Enterobius vermicularis	1 (50)	1 (50)	2 (100)
Entamoeba coli	17 (68)	8 (32)	25 (100)
Entamoeba histolytica	1 (100)	0 (0)	1 (100)
Blastocystis hominis	7 (70)	3 (30)	10 (100)
Giardia lamblia	152 (80.42)	37 (19.58)	189 (100)
Hymenolepis nana	3 (60)	2 (40)	5 (100)
Total	185 (77/7)	53 (22/3)	238 (100)

Spatial analysis

To conduct locational analyses, the relevant information was fed into a locational data bank in ArcGIS10.4.1 software, and the distribution maps of the disease in various years were drawn in ArcMap. The kriging interpolation analysis was run to detect the high-risk areas of the disease in the province ($P < 0.05$). To construct the ecological niche model of the *G.lamblia* parasite, the geographical coordinates of 56 areas in Ardabil Province, from which two or more cases of parasite infection were reported, were entered into Excel, saved by the CSV extension and finally analyzed by Maxent3.3 software. 19 bioclimatic variables as well as altitude layer were downloaded from the worldclim database with a spatial resolution of 1km2 (version1.4, http://www.worldclim.org/bioclim) (Table 1).

Table2 Incidence of intestinal parasites in humans based on male and female in Ardabil province, northwestern Iran

No	Variable	Description	Percent contribution
1	Bio16	Precipitation of wettest quarter (mm)	41.1
2	Bio3	Isothermality: (Bio2/Bio7) × 100	17.8
3	NDVI	−1 to +1	17.5
4	Slope	Slope of the area (%)	7.4
5	Bio2	Mean diurnal range: mean of monthly (max temp–min temp) (°C)	4.6
6	Bio19	Precipitation of coldest quarter (mm)	3.2
7	Bio13	Precipitation of wettest month (mm)	2.2
8	Bio11	Mean temperature of coldest quarter (°C)	2
9	Bio14	Precipitation of driest month (mm)	1.4
10	Bio18	Precipitation of warmest quarter (mm)	0.7
11	Bio4	Temperature seasonality (SD s 100)	0.5
12	Bio12	Annual precipitation (mm)	0.5
13	Bio15	Precipitation seasonality (coefficient of variation)	0.5
14	Bio7	Temperature annual range (Bio5−Bio6) (°C)	0.2
15	Aspect	direction of slope (Degree)	0.2
16	Bio6	Minimum temperature of coldest month (Ŷ°C)	0.1
17	Bio8	Mean temperature of wettest quarter (°C)	0
18	Bio5	Maximum temperature of warmest month (°C)	0
19	Bio17	Precipitation of driest quarter (mm)	0
20	Bio9	Mean temperature of driest quarter (°C)	0
21	Bio10	Mean temperature of warmest quarter (°C)	0
22	Bio1	Annual mean temperature (°C)	0
23	Altitude	Elevation from the sea level (m)	0

Results

Epidemiological aspects

A total of 238 cases of intestinal parasite disease were registered and reported during the study period, 77.7% of which were males and 22.3% females. Seven types of intestinal parasites were prevalent in Ardabil Province with *G.lamblia* species (79.4%) being the most prevalent one and *E.histolytica* species (4%) the least prevalent one (Table2). The seasonal prevalence trend shows that the prevalence rate of intestinal parasites was the highest in February and March and the lowest in January and October (Fig. 2). In terms of age groups, the results revealed that 52.5% of cases belonged to the 41–60 age group, 28.2% to the 21–40 age group, 13.9% to the 61–80 age group, 3.4% to under 20 age group and 2.1% to above 80 age group with no significant differences among the groups ($P < 0.05$). It was observed that 87% of cases were reported from the rural areas and 22% from the urban areas. Moreover, 90% of infected patients lived in families with four members and 10% in families with fewer than four members; 60% were self-employed businessmen, 29.5% were farmers and ranchers and 10.5% had other occupations.

Spatial analysis

A total of 56 areas in Ardabil Province reported cases of intestinal parasites in the study period of which 87% reported in rural areas. The results of interpolation analysis showed that there was one hotspot in the province that the vast area located in the center of the province with an incidence risk of up to 8 % (Fig. 3).

Fig. 3 Kriging interpolation of Giardia lamblia in different counties of Ardabil Province of Iran including infected sites, 2020 ▶

Ecological niche model

The ecological niche model of the *G.lamblia* parasite demonstrates that the most significant ecological niche of this species is located in the center of Ardabil Province, highlighted in Fig. 4 by warm red colors. This area is vast and connected to other central and northern areas. The most important climate and environmental factors affecting the ecological niche of this parasite are Precipitation of wettest quarter (Bio16) (41.1%), Isothermality (Bio3) (17.8%), and the NDVI(17.5%).The results of the sensitivity test in the identification of appropriate habitat for this parasite in the center of the province revealed that the evaluation of the test regarding the determination of ecological niche was adequate (more than 0.5); the calculated number (0.857) is marked by a red line in Fig. 5.

Discussion

Given the improvement of personal and public health in recent decades, several risk factors underlying the transmission of parasitic diseases have been removed so that marked changes have been observed in this regard. Asgari conducted two studies in 1989 and reported that Iranian people were infected by 32 different types of worms (G. 1990) and that one-third of the Iranian population seems susceptible to being infected by ascaris worms (Daryani et al. 2012). Studies in other parts of the world, such as

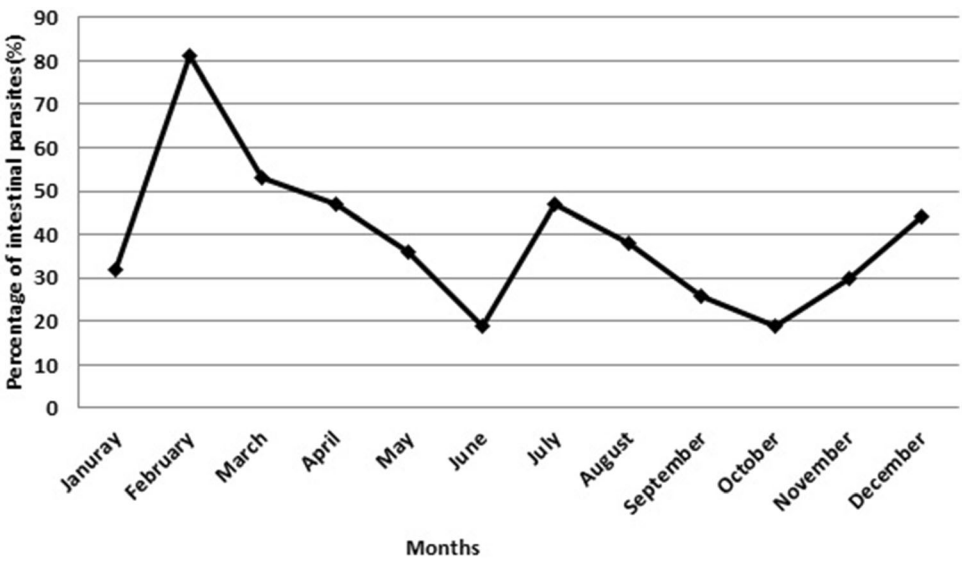
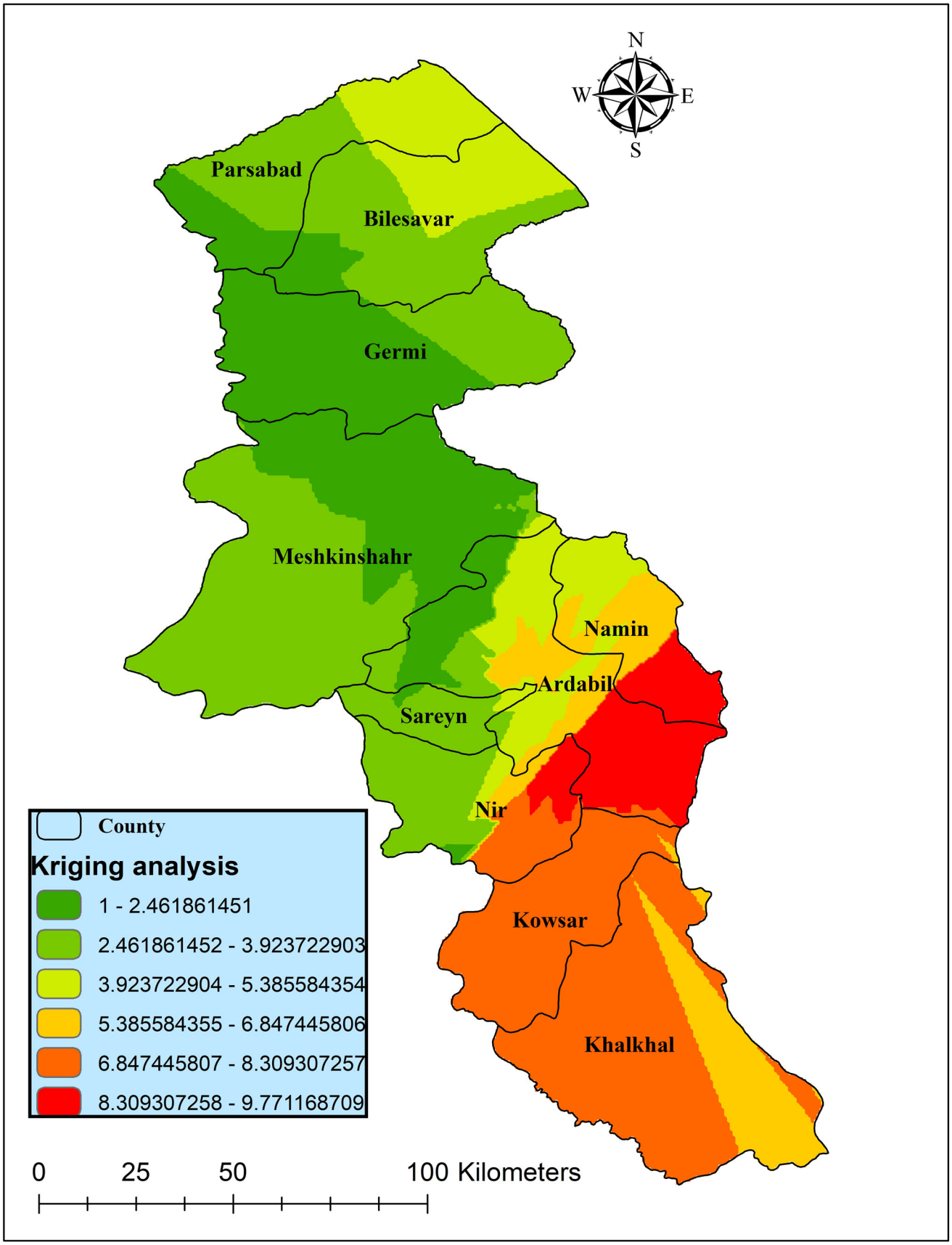


Fig. 2 Percentage of intestinal parasites by month in Ardabil province, northwestern Iran, 2020


N
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Kriging analysis
1 - 2.461861451
2.461861452 - 3.923722903
3.923722904 - 5.385584354
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8.309307258 - 9.771168709
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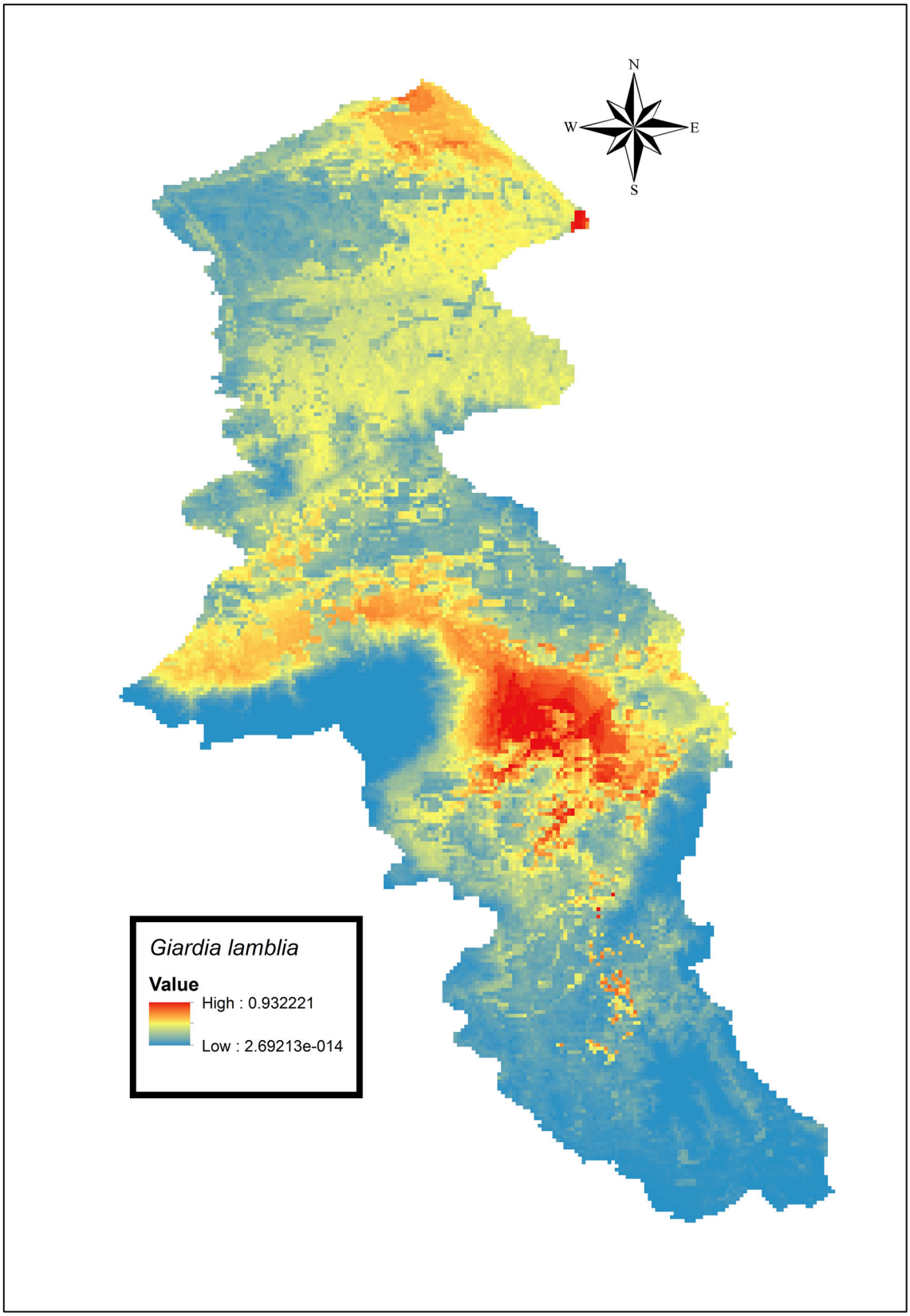

Fig. 4 Ecologically suitable areas for Giardia lamblia occurrence in Ardabil Province, northwest of Iran,2020

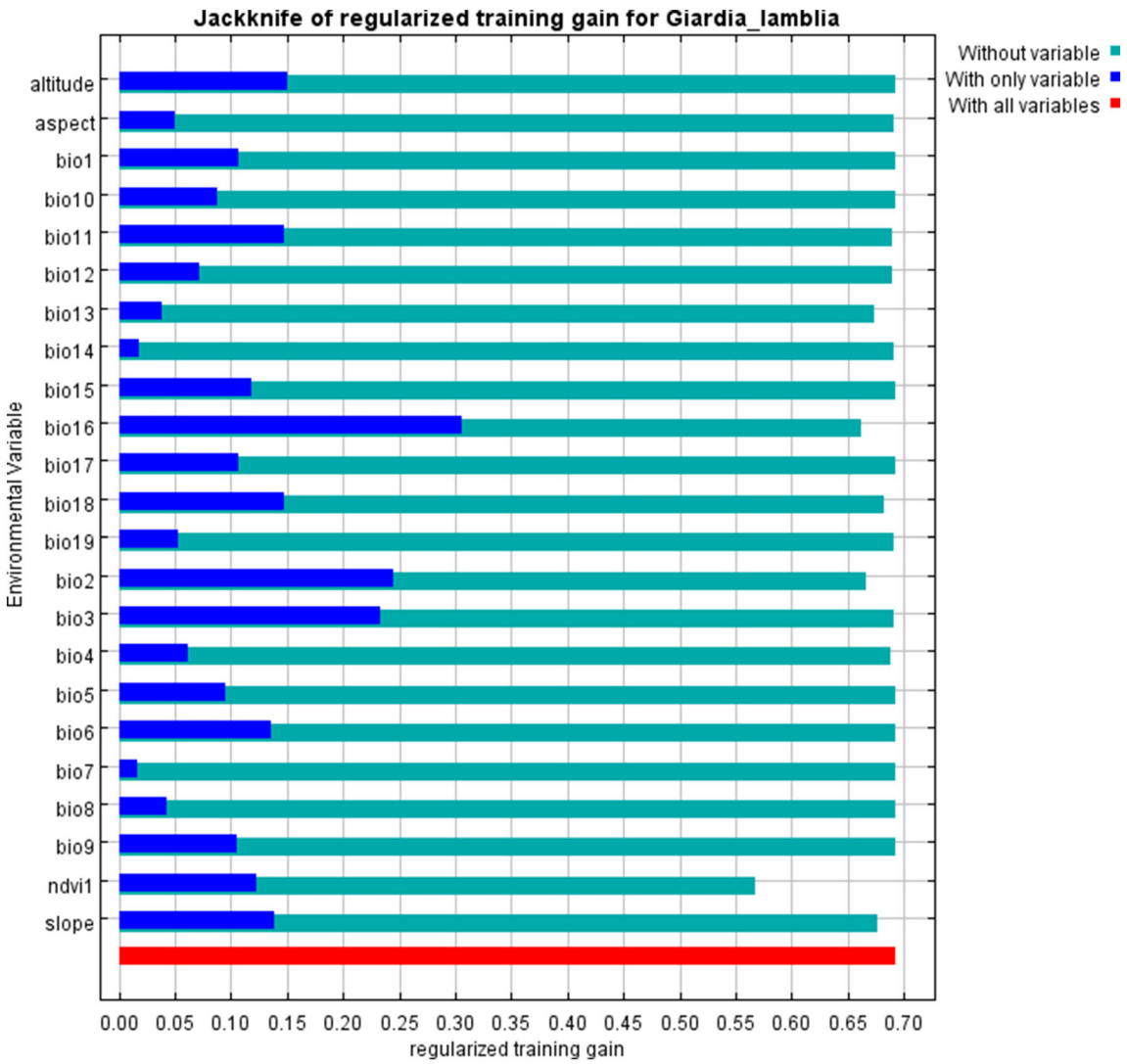

Fig. 5 Result of jackknife test of variables importance for Giardia lamblia in Ardabil Province, northwest of Iran,2020

Goncalves et al. (Gonçalves et al. 2005), have revealed that the prevalence of intestinal parasites is high in the Sumidouro population. The findings of this study also revealed that intestinal parasites infecting Iranian people in Ardabil Province are diverse, and *G.lamblia* and *E.coli* are the most prevalent species of this parasite. Hazrati Tapeh et al. carried out a study in Urmia and observed that the prevalence rate was 10.3% for *G.lamblia* and 6.3% for *E.coli* (Hazrati Tappeh et al. 2014).

It was also found in this study that males were significantly more infected than females ($P < 0.05$), and the more active, working group of the society (the 40–60 group) were more infected than other age groups. In agreement with the findings of this study, another study conducted in Ardabil Province reported that males were infected three times more than females and that more than 80% of the infections happened in the 20–50 age group (Babaei et al. 2018). No study has investigated the ecological niche of intestinal parasites in Iran and its northwestern regions so far, but a few have been conducted focusing on blood parasites and their carriers such as visceral leishmaniasis and malaria (Adham et al. 2020; Halimi et al. 2014; Hanafi-Bojd et al. 2011; Khamesipour et al. 2020; Moradi-Asl et al. 2019). The current study is the first to investigate the ecological niche model of one type of intestinal parasite (*G.lamblia*), locating two hotspots for the disease: one in the center of Ardabil Province (41–45% prevalence rate) and the other in the northern section of the province and the center of the Republic of Azerbaijan (23–30% prevalence rate).

Such information can be utilized in the educational, preventive and control sectors of the health system in the region. A study in the north of Iran investigated the geographical distribution of *G.lamblia* in 2018 and

demonstrated that there was a hotspot in the center of Mazandaran Province, and the distribution of this parasite had a significant correlation with age, occupation and season (Siyadatpanah et al. 2018). Similarly, the results of another study revealed that the prevalence rate of the giardia parasite was very high in Brazil with poor suburban areas in the cities having the highest prevalence rate due to water contamination and a lack of easy access to public healthcare systems (Coronato Nunes et al. 2016). The most significant climate variables affecting the ecological niche and geographical distribution of giardia in this study were Bio16, Bio3, and the NDVI. Environmental and climate changes have impacts on the density and ecology of different species and can result in the increase or decrease of species (Hijmans and Graham 2006). Similar studies in New Zealand have also reported that precipitation and temperature can significantly affect the frequency of giardia (Britton et al. 2010), in line with the results of a study in California emphasizing that the NDVI can directly impact giardia (Miller et al. 2007).

Conclusion

The results of the study showed that *G.lamblia* is the most prevalent intestinal parasite in Ardabil Province; moreover, one important hotspot was also detected in the province that can provide useful information regarding the management and control of this parasite. The most important factors affecting the ecological niche of giardia are Bio16 and Bio3 that can directly impact the prevalence and frequency of this parasite in the region.

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