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The Impact of Environmental Parameters on Hard Tick Distribution in North Central Iran

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Hard Tick Distribution in North Central Iran

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Abstract

Ticks are considered one of the most significant pathogen transmitters, affecting animal and human health worldwide and causing severe economic losses. In the present study, conducted between 2020 and 2021, 274 small ruminants were sampled in six regions of Semnan Province, and tick samples were collected from their body surface. The mean infestation intensity was 4.7 ± 0.9 ticks per animal (95% CI: 3.9–5.5). *Hyalomma marginatum* and *Rhipicephalus sanguineus* were the most prevalent. The implementation of the Maxent model on the *Hyalomma* demonstrated that an increase in the average annual temperature from -5°C to 20°C, and a decrease in precipitation of the wettest quarter of the year, increases the probability of finding the tick. For *Rhipicephalus*, an increase in the average annual temperature from -5°C to +5°C increased the probability of finding the tick. The onset of precipitation during the driest month significantly reduced tick abundance. Due to global warming, hard tick populations are expected to increase in these areas in the coming years.

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Introduction

Ticks, as external and blood-sucking parasites, are considered the most significant pathogen transmitters, affecting human and animal health worldwide and causing many problems in veterinary and medical practice (1). The importance of these parasites is associated with their role in transmitting dangerous viral, bacterial, and parasitic diseases such as Crimean-Congo hemorrhagic fever, Q fever, tick-borne relapsing fever, tularemia, tick-borne paralysis, and Lyme disease in humans, as well as babesiosis, theileriosis, and anaplasmosis in livestock (2). In addition to disease transmission, ticks can affect livestock by damaging the skin, causing anemia, reducing production, producing toxins, and causing weight loss (3).

As the climate is desirable for the growth and development of ticks, tropical and sub-tropical regions (such as Iran) are mainly affected by tick-borne diseases. In Iran, the most common species of hard ticks belong to the genera *Hyalomma*, *Rhipicephalus*, *Haemaphysalis*, *Dermacentor*, and *Ixodes*.

In terms of the relationship between ticks and diseases, *H. anatolicum* is the main vector for *Theileria annulata*, *Th. lestoquardi*, *Th. equi*, and Crimean-Congo hemorrhagic fever virus (4). *Rhipicephalus* species act as transmitters of ovine babesiosis and ovine ehrlichiosis (5).

The distribution and abundance of ticks and tick-borne diseases are mostly influenced by biotic factors, including host density and their behavior, movement, and environmental factors such as land use, habitat modification, and climate change (6, 7). This establishes the theoretical framework linking climate variables, particularly temperature and precipitation, to tick ecology and survival, especially during off-host periods.

According to data from the Veterinary Organization, approximately 1.6 million sheep and goats are distributed across various regions of Semnan Province. These small ruminants play a crucial role in preserving genetic resources, enhancing production, and supporting rural livelihoods. However, despite their importance, comprehensive data on the prevalence of ticks infesting these animals and the environmental factors influencing their distribution remain scarce in this province. Considering that tick abundance and diversity are strongly influenced by climate variables such as temperature, humidity, and precipitation, understanding their ecological dynamics in the specific climatic context of Semnan Province is essential. Therefore, this study focuses on Semnan Province to bridge these knowledge gaps by assessing tick species distribution and analyzing the impact of climatic factors on tick prevalence in this ecologically and economically significant region.

Materials and Methods

The Study Area

The present study was conducted from May 2020 to June 2021 in different areas of Semnan Province, located in the range of 35°14'5" N and 53°55'15" E. The climatic conditions of the study area can be divided into two forms: i) Extreme semi-desert climate that is specific to the plains, salt desert, and parts of the northern and central plateaus of Iran, and includes parts of Semnan Province, including Garmsar and Ben Kouh. In these places, precipitation is low, and it usually rains in early spring and, in some years, in summer. ii) Mild semi-desert climate, which includes Semnan, Shahrud, and Damghan, in addition to different parts of Iran. Rainfall in these areas usually occurs in autumn and spring, but the highest rainfall occurs in winter. The climate of the area is influenced by the hot and dry air currents of the desert plain, but factors such as distance from the sea, the direction and length of the mountains, the height of the place, and the winds are also effective.

Sampling, Preparation, and Identification of Samples

Based on Morgan's method with a confidence level of 95% and an error rate of 5%, 274 small ruminants (65 from Semnan and Mahdishahr, 72 from Damghan, 57 from Garmsar and Aradan, and 80 from Shahrud) were sampled in the area and tick samples were collected from their body surface. The sampling method was systematic. After selecting the region, the sampling was randomly carried out on several herds that had been in the region for at least two weeks (with the cooperation of the veterinary unit). First, the whole body of the animals, including the head, neck, ears, under the tail, and around the anus, groin, and around the breast and genitals was carefully checked for ticks. The isolated ticks were transported to the laboratory in closed containers with a piece of wet cotton. In the laboratory, the ticks were stored in the AFA solution near the boiling point for 1 to 2 minutes so that their bodies could achieve the required elongation for detection. Next, each sample was transferred to a microtube containing 70% alcohol. Finally, the genus and species of the ticks were determined using available diagnostic keys under a stereo microscope.

Investigating the Effect of Environmental Variables on the Distribution of Ticks

To determine the potential areas for the presence of tick species and to identify the most important variables affecting their development, 19 environmental variables that are ecologically important for various ticks of the Ixodidae family were chosen from the WorldClim database at a spatial scale of 30 seconds (about 900 meters) (8). Then, using the methods of Pearson's correlation coefficient (±0.8) and principal components analysis (PCA) (9) and also considering the importance of the variable from an ecological perspective, 13 variables as described in Table 1 were selected for the Maxent model (10).

Maxent Model (Maximum Entropy)

The Maxent model (Phillips et al., 2006) is a species distribution model derived from machine learning used for the prediction of the potential spread of species. This model only needs attendance data and environmental information (11). Methods that apply only to attendance data are simple and require adjusting the relationships of known attendance events with predictor variables such as regional average temperature and precipitation (12). Research indicates that even when the sample size is small, the Maxent method can provide the highest prediction accuracy and acceptable results (13). In the first step, the input environmental layers are entered into the model based on the observed points. The Maxent model determines the best distribution function between the locations of hard ticks and the environmental variables of the area based on the concept of maximum entropy, then generalizes the mentioned function throughout the studied area. Finally, the model maps the distribution of hard ticks (10).

Evaluation of the Maxent Model

The Maxent model evaluation is performed using the error matrix provided by Fielding and Bell (1997) (14), with four possible results shown in Table 1. In this table, (a) is the number of points where the target species is present and correctly predicted by the model (true positive), (b) is the number of points where the target species is absent but predicted by the model (false positive), (c) is the number of points where the species was not predicted by the model, but was observed in the real state (false negative), (d) is the number of points where the species was not predicted by the model and was not observed in the real state (true negative) (14). The area under the curve (AUC) of the ROC plot is used to assess the model. In evaluating the model at different thresholds, the following two indices are determined, and then their curves are drawn in a two-dimensional plot. The area under the curve (AUC) represents the model's performance, where a value closer to 1 indicates better performance. Table 2 presents AUC values classified according to Swets (1988) (15).

Table 1. Error matrix and its components

Real status		
False positive (b)	True positive (a)	Predicted status
True negative (d)	False negative (c)	

Relation 1 Sensitivity = a / (a+c)
Relation 2 Specificity = d / (b+d)

Table 2. Classification of AUC Values according to Swets (1988)

Coefficient classification	Domain
Weak	0.5-0.7
Acceptable	0.7- 0.9
High	0.9-1

Results

Abundance of Isolated Species

A total of 1,282 adult hard ticks were collected from 274 small ruminants (sheep and goats). The mean intensity of infestation per infested host was 4.7 ± 0.9 ticks (95% CI: 3.9–5.5). Among the identified species, *Hyalomma marginatum* and *Rhipicephalus sanguineus* were the most prevalent (Table 3).

Statistical comparison between host species revealed no significant difference in overall tick infestation prevalence (χ^2 = 1.24, p = 0.27). The highest mean infestation intensity was recorded in Garmsar and Shahrud (39.7 ± 4.1 and 6.46 ± 1.2 ticks per infested animal, respectively), whereas Semnan and Damghan showed the lowest values (2.36 ± 0.6 and 1.81 ± 0.5 ticks per animal, respectively). However, the differences among the studied regions were not statistically significant according to one-way ANOVA (F = 2.03, p = 0.09).

Regarding the attachment sites, a total of 445 ticks were collected from the perineal and mammary regions (mean ± SD: 2.92 ± 0.8; 95% CI: 2.1–3.7) and 837 ticks from the ear region (mean ± SD: 6.97 ± 1.1; 95% CI: 5.6–8.3). Approximately 98% of the ticks collected in Garmsar and Semnan were attached to the ear, while in Damghan, Mahdishahr, and Shahmirzad, the majority were obtained from the perineal and mammary areas. Among the ticks collected from the perineal and mammary regions, 76% belonged to the genus *Hyalomma*, whereas 24% were identified as *Rhipicephalus*. In contrast, 95% of ticks collected from the ear were members of the genus *Rhipicephalus*.

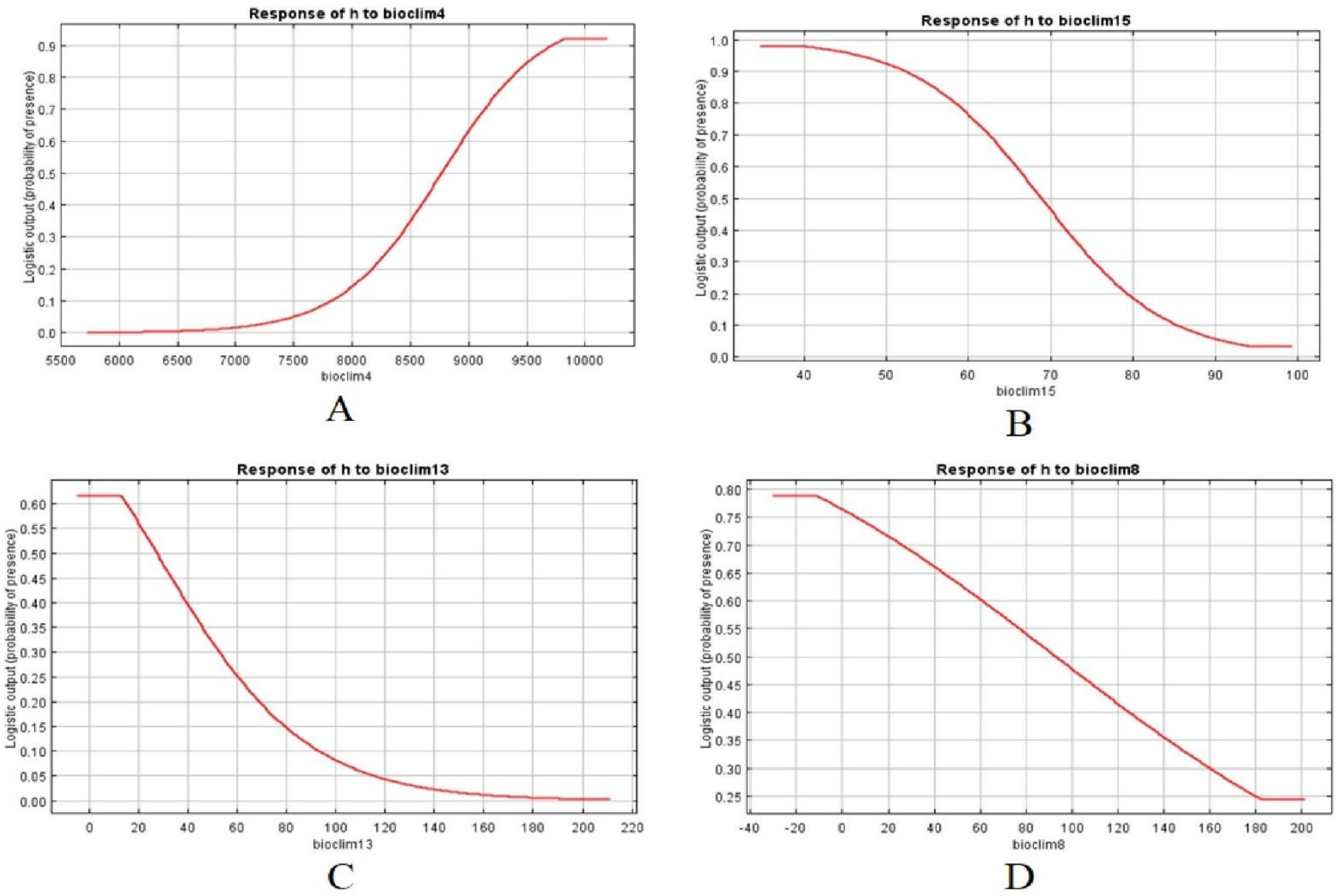

Figure 1. Species response to four important variables on the distribution of *Hyalomma* A) Bio4 (temperature seasonality, standard deviation x 100); B) Bio15 (precipitation seasonality, CV); C) Bio13 (precipitation of the wettest month); D) Bio8 (average temperature of the wettest quarter of the year)

A statistically significant association was detected between the tick genus and the attachment site ($\chi^2 = 6.84$, $p = 0.009$), suggesting that the preferred attachment region of ticks is influenced by their genus. In contrast, no significant association was observed between the host species (sheep or goat) and either the tick genus or the attachment site ($p > 0.05$). These findings indicate that tick host preference is non-specific, while site selection for attachment is primarily determined by tick genus and geographical location.

Analysis of the Effect of Environmental Variables on the Distribution of Hard Ticks

The Maxent model was employed to analyze the relationship between the presence of hard ticks in the environment and climate variables. In this model, based on the climate variables of the last 50 years recorded in the software, the possible relationship of the hard ticks with the variables was assessed. Then, the software looks for areas with environmental conditions similar to the presence points and the areas where it is likely to be present. In the current study, 22 environmental variables (Table 4) were analyzed for each tick sample.

Table 3. Isolated ticks from different areas of Semnan Province

Isolated species	Average number of ticks on each infested animal	Prevalence (%)
D. marginatus	1	0.36
H. anatolicum	2.75	1.46
H. asiaticum	2.71	5.1
H. excavatum	2	0.36
H. marginatum toranicum	4	1.55
H. marginatum	1.75	34.43
Hyalomma spp.	3.25	1.46
Rh. bursa	4.27	17.21
Rh. sanguineus	6.91	31.13
Rhipicephalus spp.	2.16	4.76

Distribution of *Hyalomma*

The results of the model components demonstrated that the variables of seasonal temperature (standard deviation x 100) (44%), seasonal rainfall (36%), rainfall in the wettest season of the year (11.1%) and average temperature of the wettest season of the year (5.7%) and the average rainfall in the wettest season (3%) contributed the most in the spread of *Hyalomma* species. Figure 1 represents the response curves of *Hyalomma* species to the variables.

The implementation of the model for *Hyalomma* demonstrated that an increase in the average annual temperature from −5°C to 20°C, an increase in the minimum average temperature, and a decrease in the wettest quarter resulted in an increased probability of finding the tick. In other words, tick presence is more sensitive to shorter periods of time (such as seasons) than to longer periods (such as years). Moreover, the greater the temperature difference between the hottest and coldest months of the year, the higher the likelihood of tick presence.

Rhipicephalus Distribution

The results of the Maxent model to determine the distribution of *Rhipicephalus* tick showed that the average variables of temperature in the coldest quarter (30.9%), precipitation in the driest quarter (25.8%), seasonal precipitation (19.6%), The slope of the land (6.3%), precipitation in the coldest month of the year (6.2%), annual precipitation (2.5%), and average temperature in the wettest season (2.2%) contributed the most to the spread of *Rhipicephalus* species. The response curves of *Rhipicephalus* species to these variables are shown in Figure 2.

The implementation of the model demonstrated that as the average annual temperature rose from -5 to +5 degrees Celsius, the probability of finding the tick increased. The onset of precipitation in the driest month significantly reduced tick abundance.

The more regular the seasonal precipitation, the more likely ticks will be found, and the more irregular the precipitation, the less likely ticks will be found. The highest probability of the tick presence was in the temperature range of -10°C to 0°C in the coldest month of the year. Increasing and decreasing the range reduced the possibility of tick presence. Furthermore, when rainfall in the coldest quarter exceeded 70 mm and annual rainfall exceeded 100 mm, the probability of tick occurrence decreased. Moreover, as the temperature rose in the wettest season of the year, the possibility of tick presence reduced.

Figure 3 presents the possible distribution of ticks isolated from sheep and goats in different parts of Semnan Province according to temperature and precipitation variables, and all referenced figures have been incorporated. The independent evaluation of the model an AUC of 0.875 for Hyalomma and 0.843 for *Rhipicephalus* species, indicating high performance of the Maxent model in estimating their distribution (Figure 4).

Table 4. Studied environmental variables

No.	Code	Environmental variable	Unit
1	Bio1	Average annual temperature	◦C
2	Bio2	Mean diurnal range	◦C
3	Bio3	Isothermality	-
4	Bio4	Seasonal temperature (SD × 100)	C of V
5	Bio5	Maximum temperature of the warmest month of the year	◦C
6	Bio6	Minimum temperature of the coldest month of the year	◦C
7	Bio7	Annual temperature range	◦C
8	Bio8	Average temperature of the wettest quarter of the year	◦C
9	Bio9	Average temperature of the driest quarter of the year	◦C
10	Bio10	Average temperature of the warmest quarter of the year	◦C
11	Bio11	Average temperature of the coldest quarter of the year	◦C
12	Bio12	Annual rainfall	mm
13	Bio13	Precipitation in the wettest month	mm
14	Bio14	Rainfall in the driest month	mm
15	Bio15	Seasonal precipitation	C of V
16	Bio16	Precipitation of the wettest quarter of the year	mm
17	Bio17	Precipitation of driest quarter of the year	mm
18	Bio18	Precipitation of the warmest quarter of the year	mm
19	Bio19	Precipitation of the coldest quarter of the year	mm
20	DEM	Above sea level	m
21	Slop	Slope	%
22	Aspect	Slope direction	-

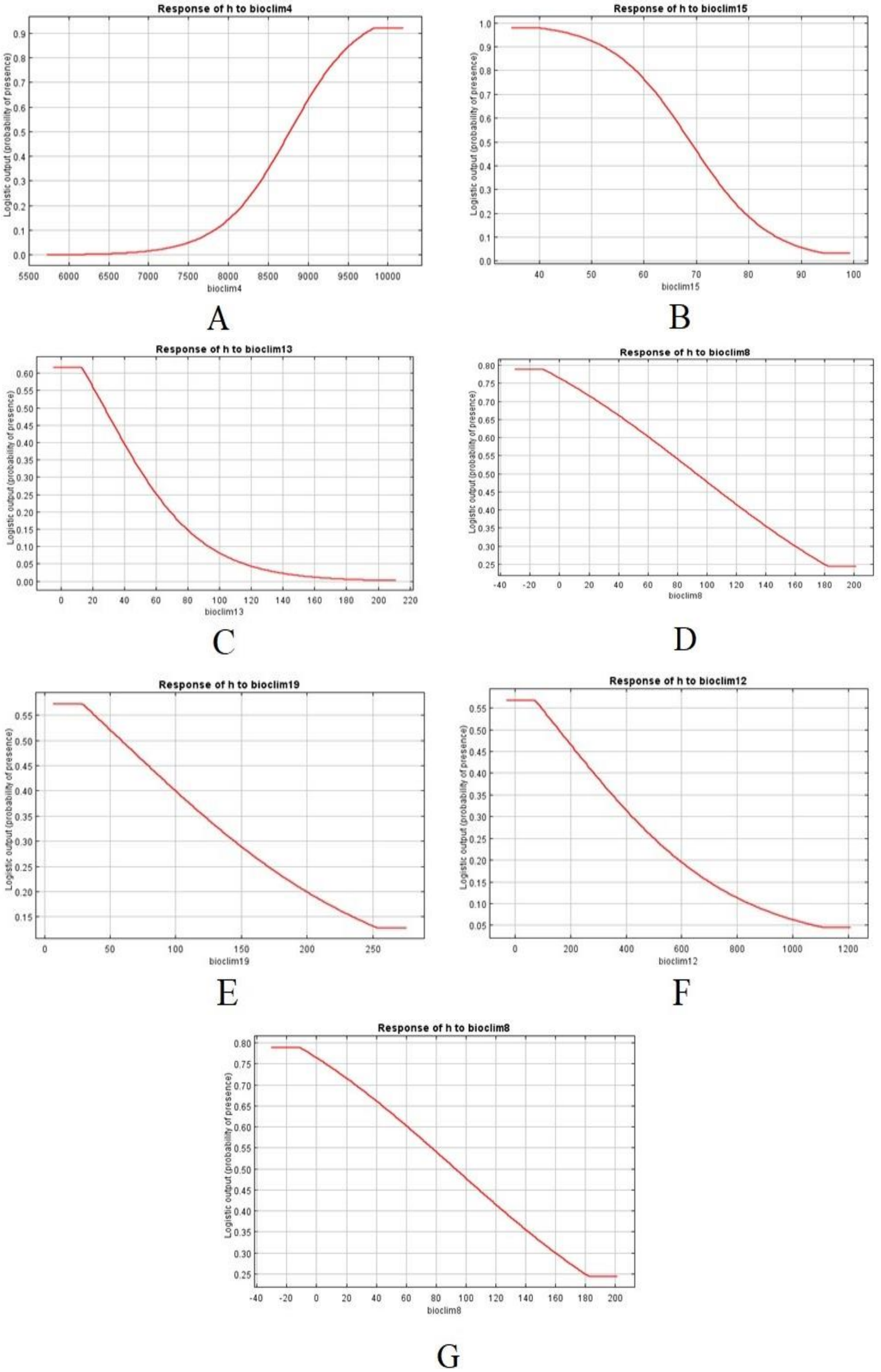

Figure 2. Species response to 4 important variables on *Rhipicephalus* distribution. A) Bio11 (average temperature of the coldest quarter of the year); B) Bio14 (precipitation in the driest month of the year); C) Bio15 (seasonal precipitation, CV); D) Bio6 (minimum temperature of the coldest quarter of the year); E) Bio19 (precipitation of the coldest quarter of the year); F) Bio12 (annual precipitation); G) Bio8 (average temperature in the wettest quarter of the year).

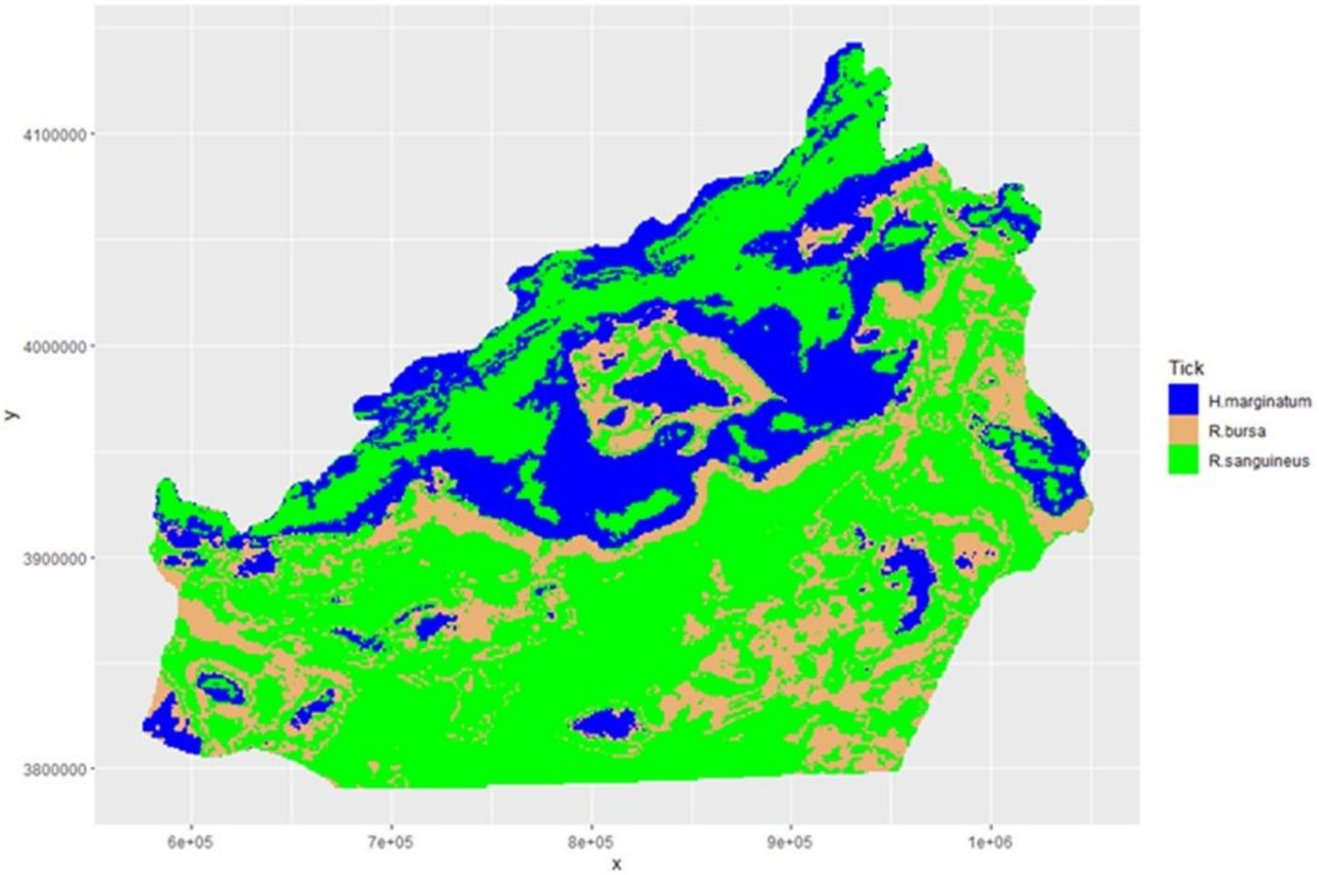

Figure 3. Possible distribution of the ticks in different areas of Semnan Province

Discussion

Ticks are considered to be one of the most significant pathogen transmitters, affecting animal and human health worldwide (16). They can act as important vectors for a large number of parasitic, viral and bacterial pathogens. In addition to their role in the transmission of pathogens, ticks also cause anemia, dermatitis, paralysis, and a decrease in livestock production (17).

In tropical and subtropical areas like Iran, domesticated animals are affected by tick-borne bacterial and parasitic diseases. In Iran, the genus *Hyalomma* is one of the common hard ticks that infest livestock and plays a significant role in the transmission of tropical theileriosis agent (18). Furthermore, *Rhipicephalus* and *Dermacentor* genera have the potential to transmit babesiosis in domestic animals (19).

In the present study, a total of 1282 hard ticks were isolated from 274 sheep and goats. The average intensity of infestation on each animal infested with ticks was 4.7. Moreover, two genera of Ixodidae, including *Hyalomma* and *Rhipicephalus* were found to be the most prevalent, which is in agreement with other studies conducted in Kerman (20), Isfahan (21), Ilam (22) and Mashhad (18). Similarly, previous investigations performed in the neighboring countries, including Pakistan (16), Turkey (23), and Saudi Arabia (24) have also reported the prevalence of these tick populations (27-30), demonstrating the predominance of *Hyalomma* and *Rhipicephalus* in Asia. However, studies show the dominance of *Ixodes* in Europe (25). The differences found in the results can be attributed to some of the diversity of climates, differences in seasons and sampling locations, sample size, location of livestock, and the use of different vector control methods (spraying or dipping) (26, 27).

In the current research, *H. marginatum* (34.4%) was found to be the most prevalent hard tick species infesting sheep and goats in the study area. This finding is in line with data from previous studies in Torbat-e-Jam, Darreh Shahr (Ilam) and Semnan, (28-30) where the species was recorded as the most common ovine tick. *Hyalomma marginatum*, also known as the Mediterranean *Hyalomma* tick, is among the most important vectors of CCHF virus.

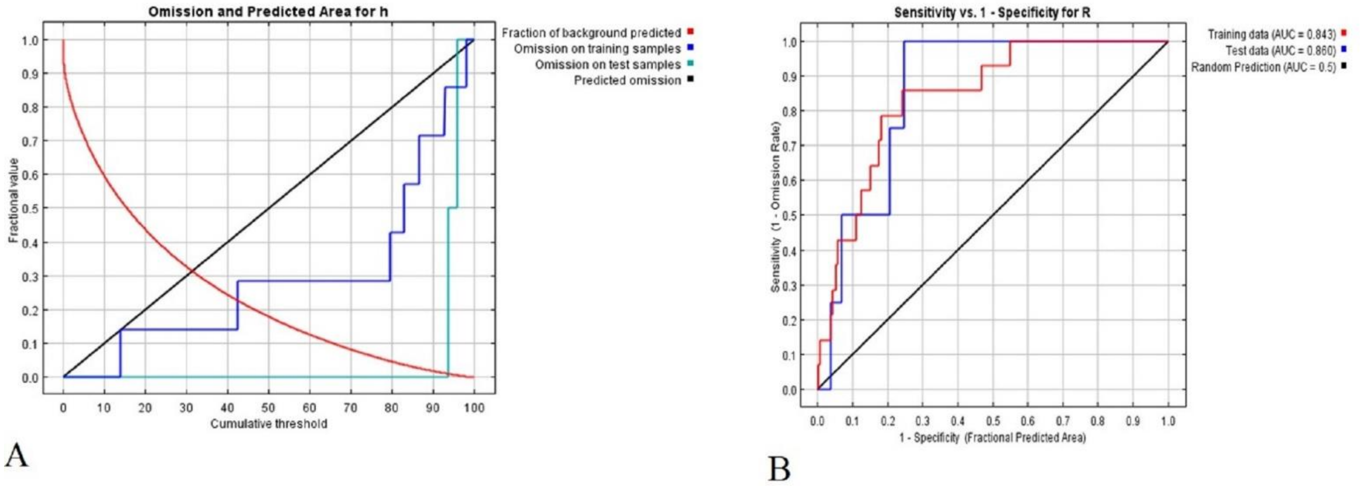

Figure 4. Selected variables based on Pearson correlation and PCA and their contribution to the distribution of *Hyalomma* (A) and *Rhipicephalus* (B) ticks

Additionally, in this study, *Rh. sanguineus* was the second most abundant tick species affecting sheep and goat. Several studies have reported *Rh. sanguineus* among the highest rate of tick infestations in livestock (31-33). Due to its ability to adapt to different ecological conditions and various hosts, this two-host tick is found in most regions of Iran as well as worldwide (e.g., Europe, Africa, South America, Syria, Egypt, and India) (34). Furthermore, studies carried out in regions with a similar climate to the study area (Garmsar and Qom), described the *Rh. sanguineus*, *Rh. bursa* and *H. marginatum* as dominant hard tick species (35, 36).

Another variable investigated was the location of ticks on the host. In this study, the preferred attachment sites in hot and dry climates were the ears, while in mountainous areas they were the perineal region and udder. In a study conducted in Semnan on a nomadic herd, ticks in hot and dry spring areas were usually attached to the ears and perineum. At the beginning of the summer season, as the herds moved to higher mountainous areas, ticks were found mostly on the sternum towards the neck (Changizi, 2014). Also, Yakhchali et al. (2004) demonstrated the perineal region and udder as the most common sites for attachment of ticks (37). The present study showed that the attachment sites of ticks to the host are strongly influenced by the geographical location and the genus of the tick. Host-seeking behavior (questing) was non-specific and can be found on both types of study animals. Altitude appears to be one of the factors influencing tick attachment site selection on the host (38).

Most ticks undergo the three-host life cycle, requiring up to three years to mature and lay eggs. They spend a short period of their life on their hosts (as parasites) and the rest freely in the natural environment. During their free-living period, ticks do not feed and only obtain the water they need through their cuticle. Given their life cycle, climate change may affect the distribution of ticks, followed by the risk of tick-borne diseases in different areas (39). In fact, it influences tick-host relationships through changes in the host populations, which act as reservoirs for tick-borne pathogens. Moreover, it has been proven that important aspects of tick biology such as survival, reproduction and questing depend on several climate-related factors, including temperature, moisture, vegetation cover, and host availability (6). A combination of possible changes in the population of ticks and their hosts, as well as the relationship between the host and the pathogen, affects the probability of transmission of tick-borne pathogens to humans and animals. Therefore, by investigating the effects of climate change on ticks, hosts, and the habitat, it is possible to learn more about how these changes influence the distribution of tick-borne diseases (30).

As described above, climate plays a major role in the distribution and abundance of ticks across seasons. However, few studies have been conducted on the role of climate in the distribution of ticks in Iran. A study in Semnan indicated that the severity of sheep and goat infestations with hard ticks was directly related to daylight duration and ambient temperature (38). Choubdar et al. (2019) showed that the average annual temperature affects the intensity of livestock tick infestation; the higher the temperature, the higher the probability of the tick's presence in the area. In addition, they documented a direct relationship between relative humidity and the presence of ticks (17).

Studies in Europe have stated that due to climate change, the distribution and spread of the population of some ticks has altered. For instance, as a result of changing the climate, *I. ricinus*-borne diseases such as Lyme disease and tick-borne viral encephalitis are increasing in humans and livestock. Similarly, the black-legged tick (*I. scapularis*), the agent of Lyme disease in North America, has expanded northward due to climate change and has spread to northern and western Canada, causing an increase in Lyme disease in humans (6).

In the present study, increased temperature and decreased annual rainfall were associated with a higher probability of tick presence on the animals. Due to global warming, the amount of annual rainfall has decreased, leading to an increase in the population of hard ticks on sheep and goats in the future. Given the importance of ticks and tick-borne diseases for human and animal health, and the impact of climate change on tick distribution and movement, it is necessary to implement more comprehensive investigations to identify tick species as well as associated risk factors in different regions of Iran.

Based on the obtained distribution patterns, our findings highlight the need for implementing integrated tick control programs that consider environmental suitability and seasonal dynamics. Control measures such as targeted acaricide application, pasture rotation, and livestock management should be prioritized in high-risk areas identified by the Maxent model. Furthermore, future studies are recommended to include longitudinal field surveys and molecular analyses to validate the model predictions, assess tick population dynamics, and evaluate the potential impacts of climate change on tick distribution and pathogen transmission.

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Authors' Contributions

Emad Changizi: Study concept and design, Analysis and interpretation of data. **Atousa Mohseni and Amin Ahmadi:** Drafting of the manuscript, Statistical analysis

Data Availability

All data analyzed in this study are included in this published article.

Ethical Approval

The authors declare that all ethical standards have been respected in the preparation of the submitted paper.

Conflict of Interest

The authors affirm that there are no competing interests with the publication of this work.

Consent for Publication

Not applicable.

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